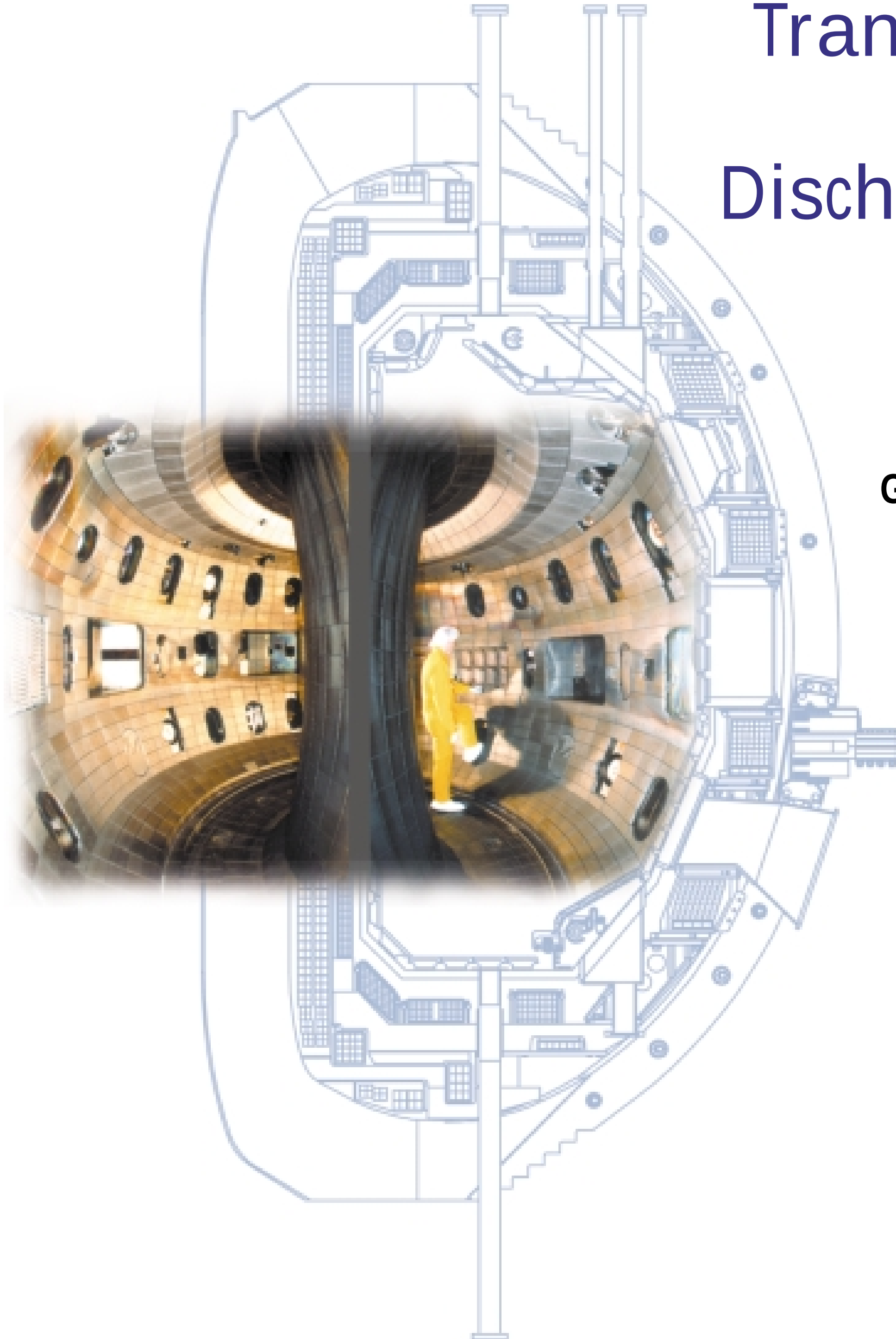

Transport Studies of L—Mode Edge Radiating Mantle Discharges with Confinement Improvement in DIII—D

by

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DIII–D
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Transport Studies of L-mode Edge Radiating Mantle Discharges with Confinement Improvement in DIII-D[1] M. MURAKAMI, M.R. WADE, Oak Ridge National Laboratory, T.E. EVANS, G.L. JACKSON, H.E. ST. JOHN, G.M. STAEBLER, General Atomics, J.E. KINSEY, Lehigh University, G.R. MCKEE, University of Wisconsin, AND THE DIII-D TEAM — Significant confinement improvements are observed with impurity injection into L–mode-edge beam-heated discharges in DIII–D. The global energy confinement increased by a factor of up to 2, with an increasing quantity of injected impurity. Neon injection produced the strongest effect in the plasma, compared with argon and krypton. Reduction of observed turbulence is correlated well with the confinement improvement. Transport coefficients decreased in all transport channels, with ion thermal diffusivity reduced to near neoclassical values. Both gyro-kinetic and gyro-fluid simulations with $E \times B$ shearing indicate that the turbulence linear stability growth rate is reduced for ion temperature gradient turbulence as a result of the impurity density gradient and dilution effects on main ion turbulence and the $E \times B$ shear suppression.

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[X] Prefer Oral Session
[ ] Prefer Poster Session

Special instructions: DIII-D Contributed Oral Session, immediately following GL Jackson

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OUTLINE

OBJECTIVES: Understand the mechanism for confinement improvement with impurity injection

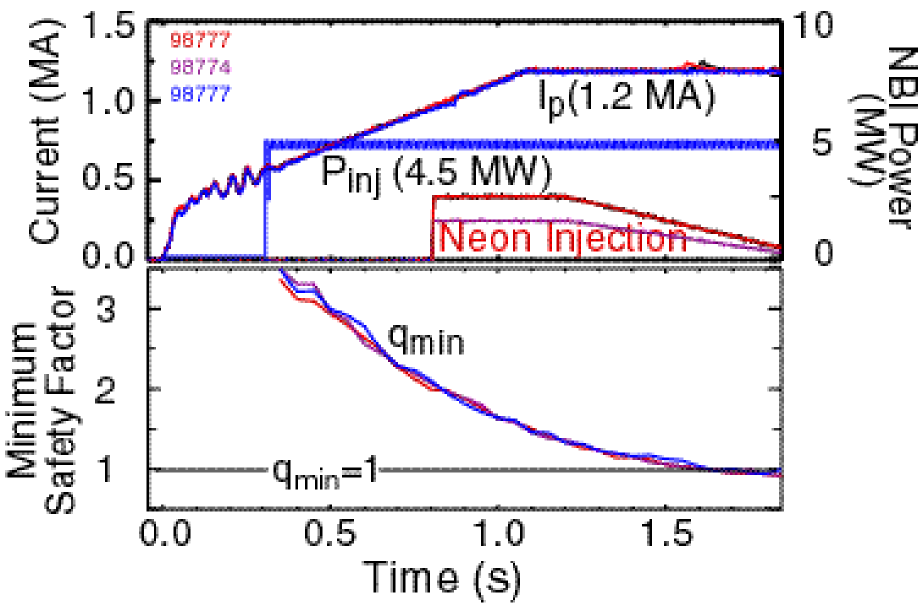
EXPERIMENT:

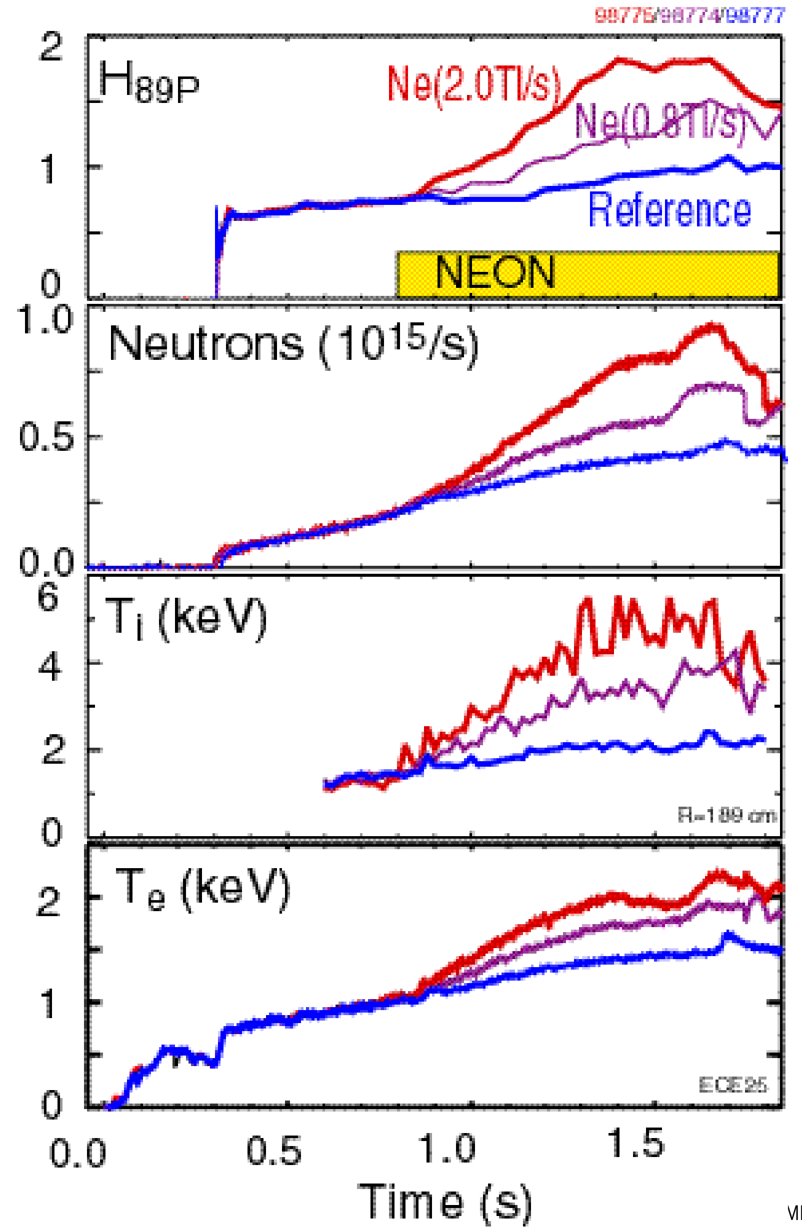
- Observed a substantial confinement improvement (up to factor of 2) with impurity injection into L-mode discharges
- Assessed effects of impurity quantity and species (Ne, Ar, Kr) on observed improvement

ANALYSES:

- Improvement correlated with strong reduction of turbulence
- → Transport analysis using TRANSP shows all transport channels improve
- → Gyro-kinetic analysis and simulations show that the confinement improvement is due to:
  - Reduction of micro-turbulence (ITG/TEM) growth rate
  - ExB shearing suppression

IMPURITY INJECTION IMPROVES CONFINEMENT PARAMETERS SUBSTANTIALLY

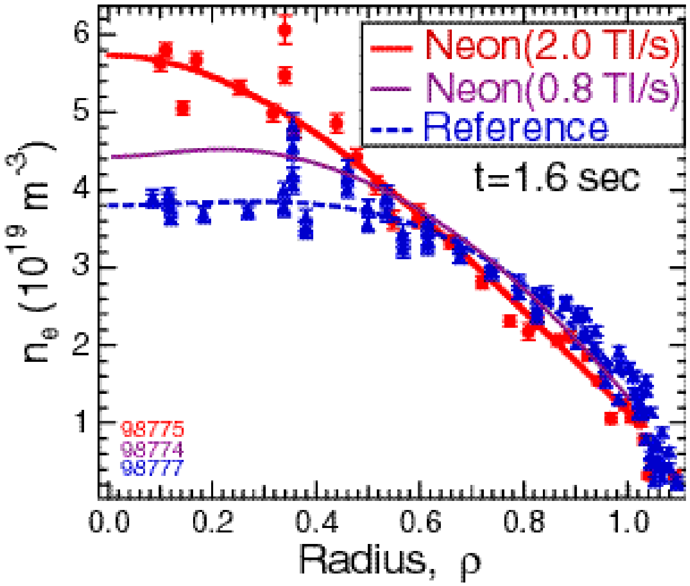




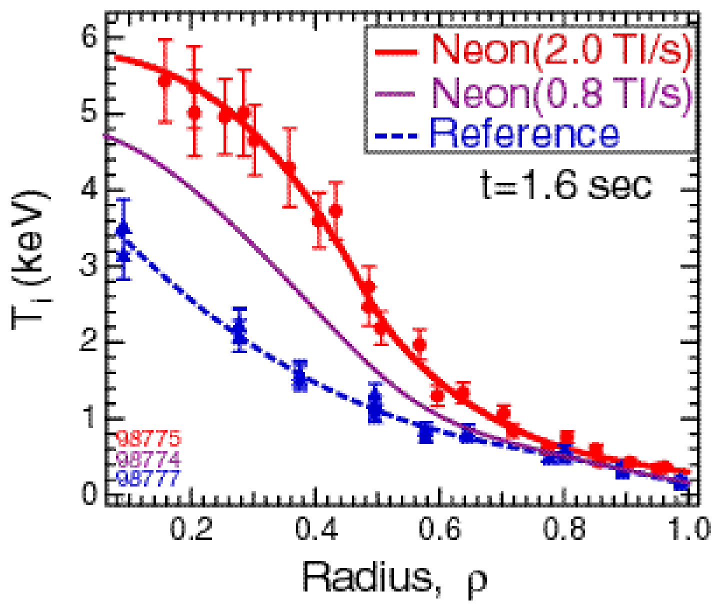
- **Early NBI q_{min}>1 to avoid sawtooth**
- **Ne, Ar, Kr (recycling gas) injected at 0.8 s and 1.2 s, quantity varied**
- **Run reference discharges with similar control parameters except no impurity puffed**

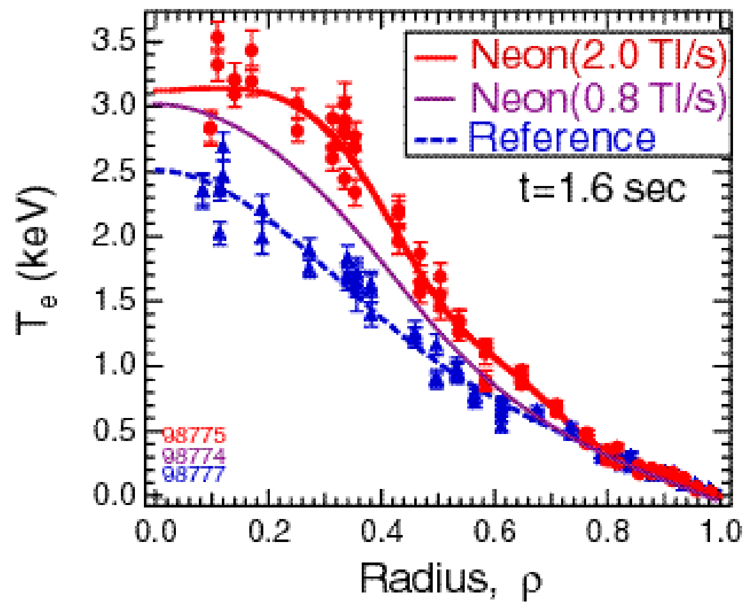
VM

NEON INJECTION PRODUCES MORE PEAKED DENSITY PROFILES, AND HIGHER AND BROADER T_i AND T_e PROFILES

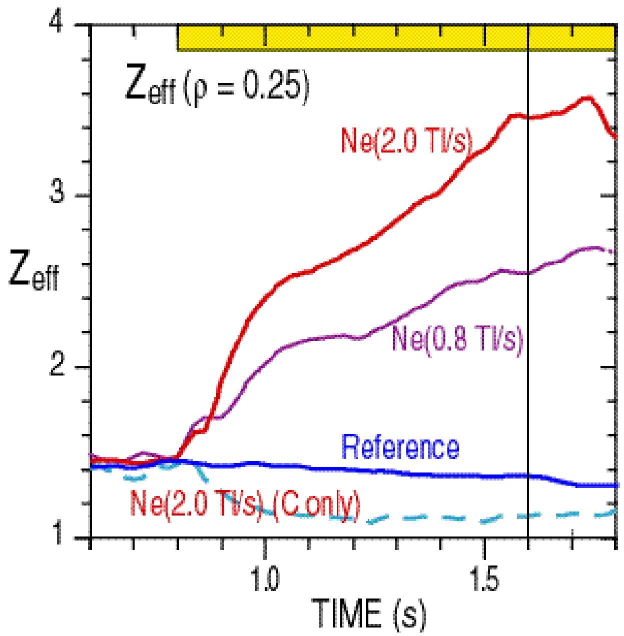


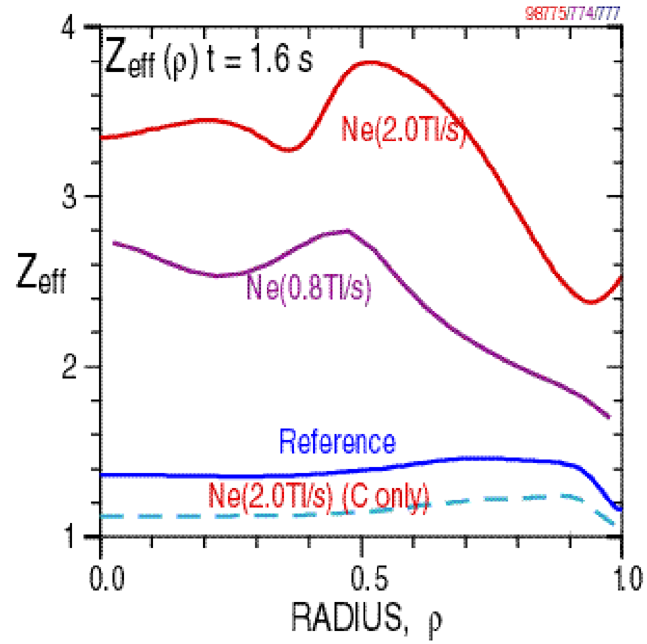
- **Density peaking factor:**
  $n_e(0)/\ n_e$ = 1.2 1.5

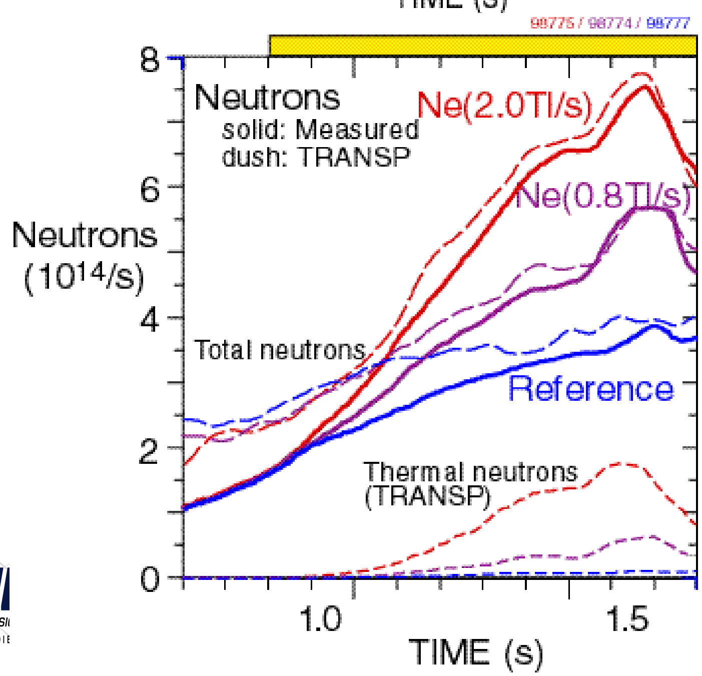




TRANSP ANALYSIS SHOWS THE INCREASE IN NEUTRONS WITH NEON INJECTION IS PRIMARILY DUE TO INCREASING THERMAL NEUTRONS



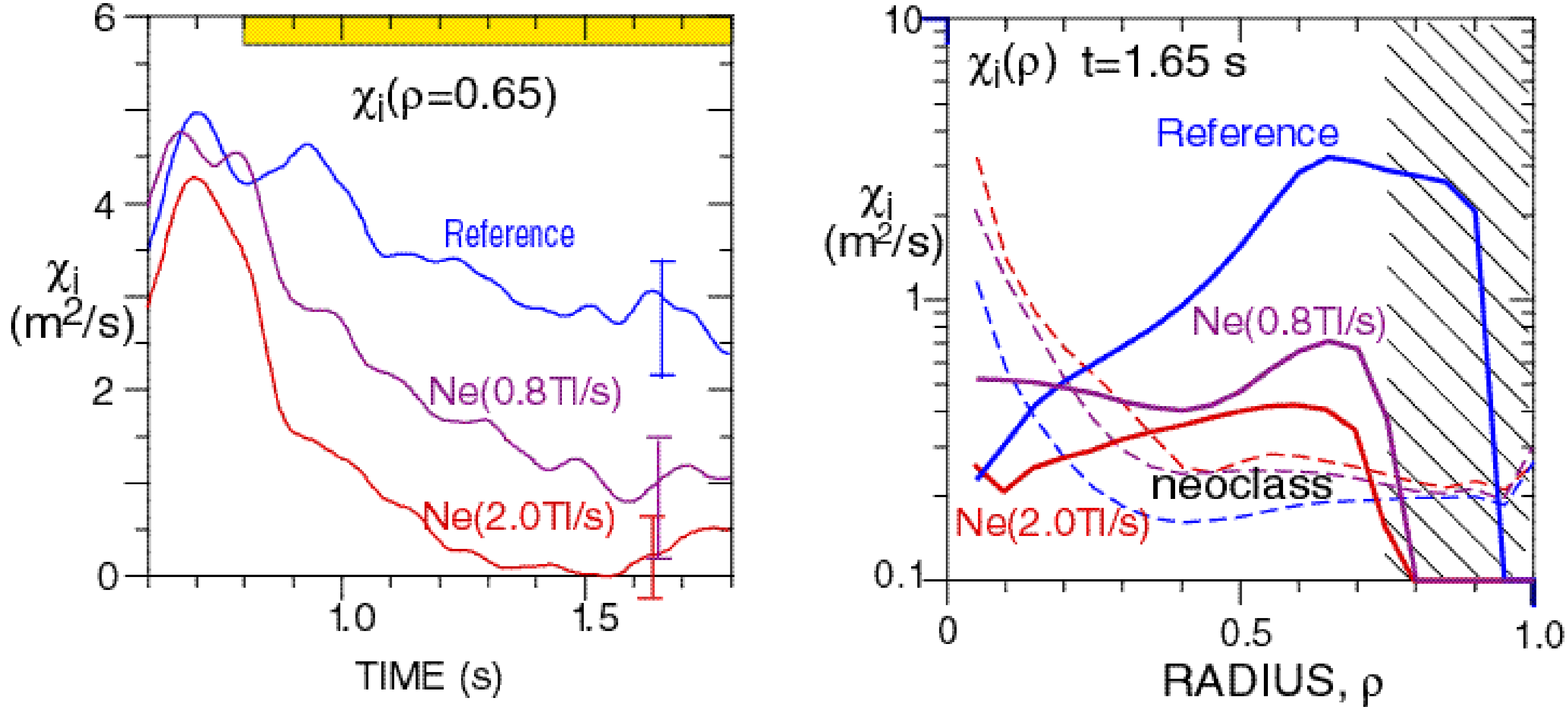




- Z_{eff} profile is determined from CER of carbon and neon
- Carbon density decreases promptly at neon puffing
- Z_{eff} increases from 1.5 (ref.) to 3.4 (full neon)

$n_{Ne}/n_e \leq 3\%$

ION THERMAL DIFFUSIVITY DECREASES STRONGLY WITH NEON INJECTION



- **(3/2)T_i n_i is used for the convection loss**

  The error bars: α=0 - 5/2 in αT_i n_i

- **χ_i is reduced to the neoclassical level throughout the profile**

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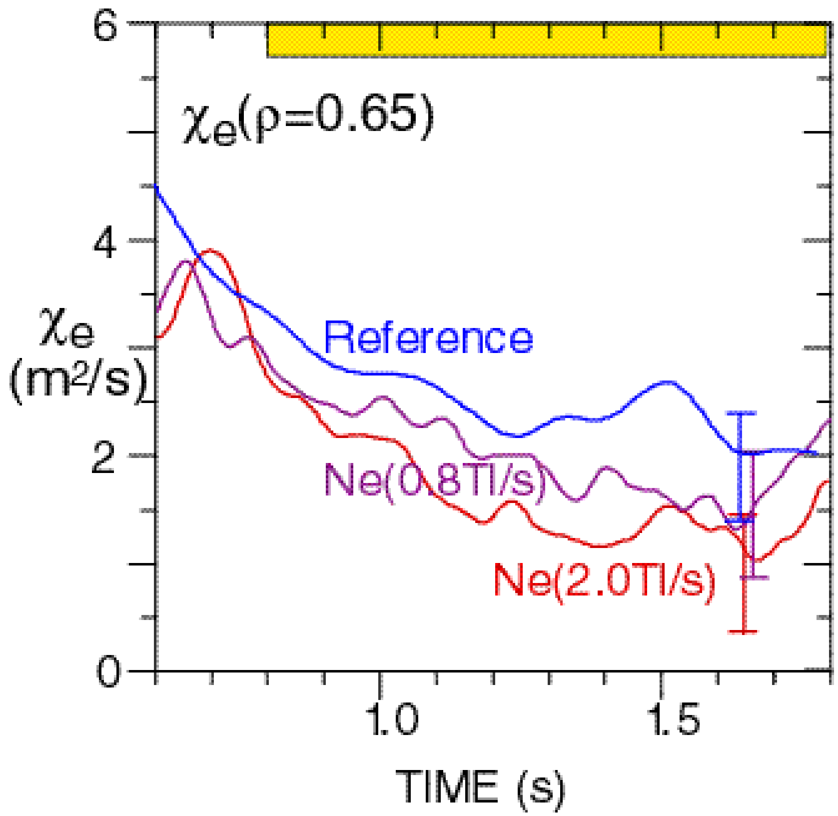
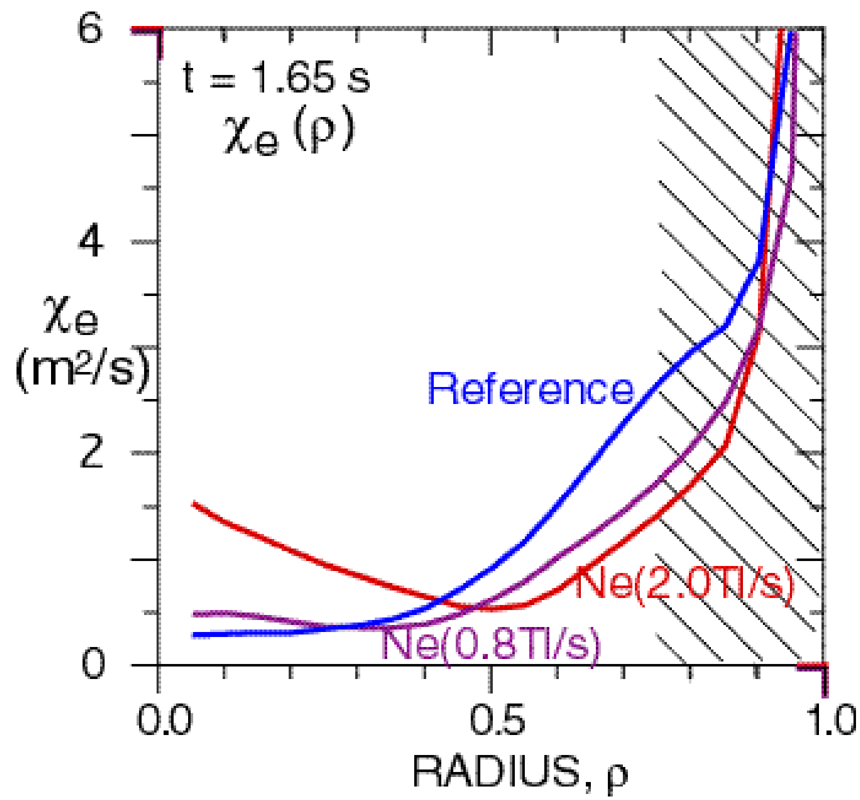
REDUCTION OF ELECTRON THERMAL DIFFUSIVITY IS MODEST





- $(3/2)T_e\ n_e$ is used for the convective loss
  [the error bars: 0 - 5/2 in $\alpha T_e\ n_e$]

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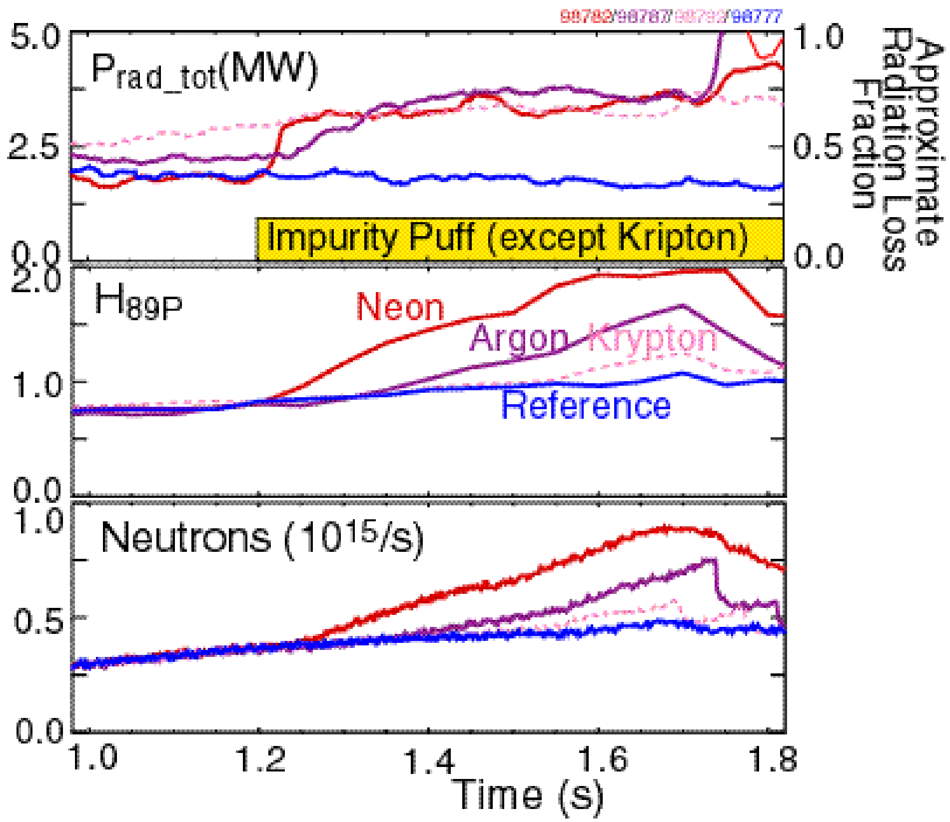
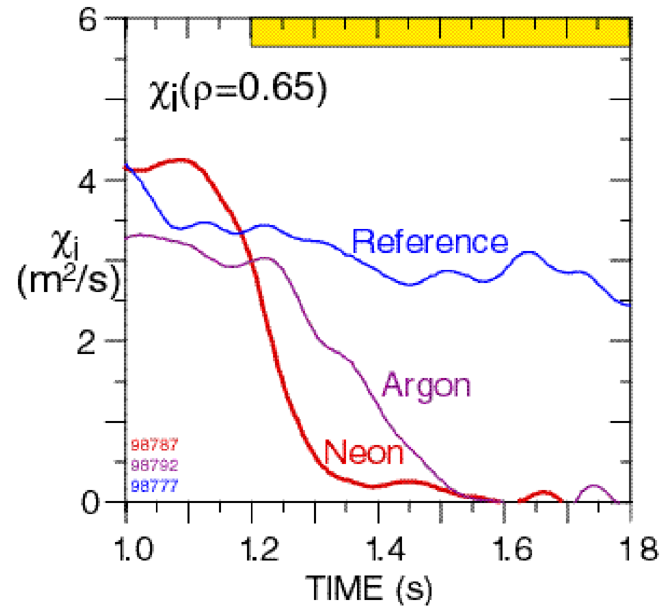
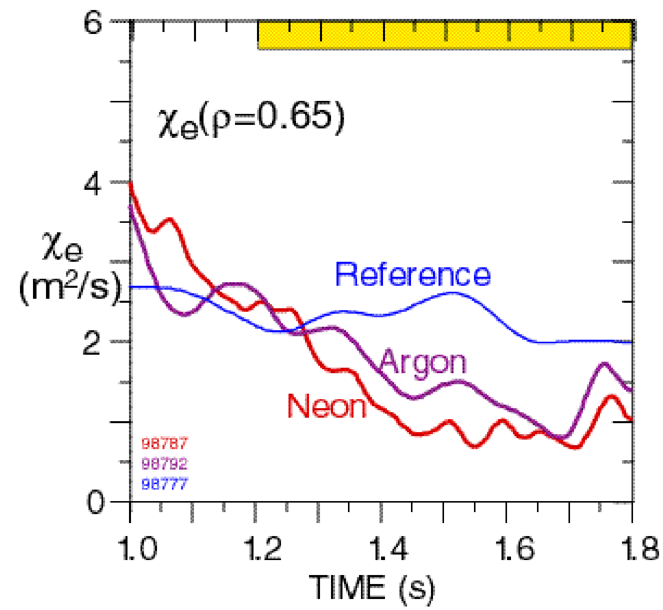
IMPURITY SPECIES SCAN WITH A FIXED P_{rad}/P_{in} SHOWS THAT ALL TRANSPORT CHANNELS IMPROVE WITH IMPURITY INJECTION, BUT ARGON RESPONDES SLOWER THAN NEON







- $P_{rad}/P_{in} \approx 75\%$ (fixed)
- Krypton injection - similar behavior but more modest transport reduction
- Impurity fraction decreases faster than atomic mass increases

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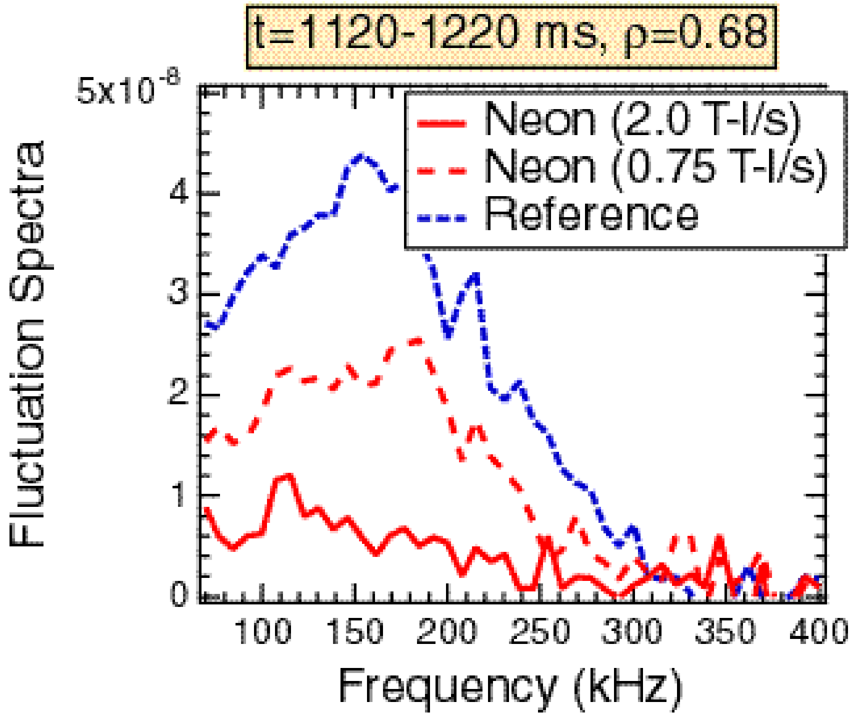
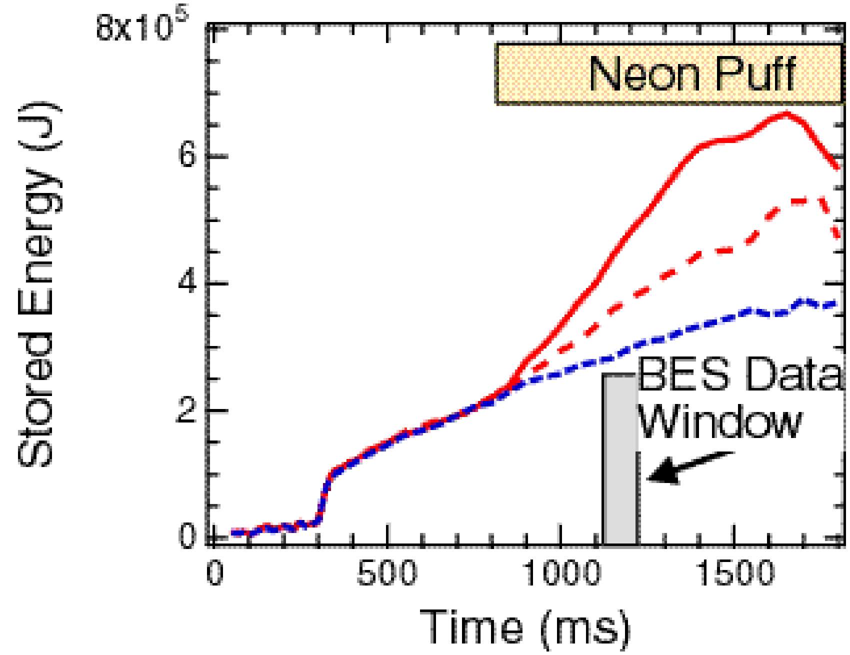
CONFINEMENT IMPROVEMENT IS CORRELATED WITH STRONG REDUCTION OF TURBULENCE WITH IMPURITY INJECTION

- **BES measures density fluctuations (k < 3 cm^{-1}) at ρ = 0.68**





- **Reduction of turbulence is also observed by FIR scattering and reciprocating probe**

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G. McKee: BI2.06

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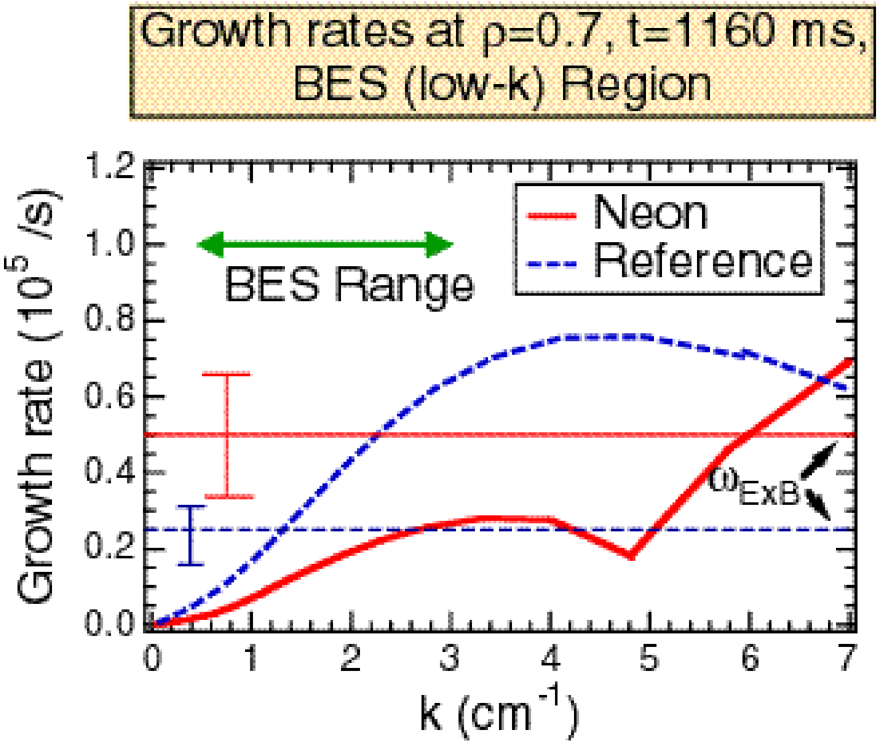
GKS CALCULATIONS SHOW THAT ITG AND TEM GROWTH RATES ARE SIGNIFICANTLY REDUCED IN LONG WAVELENGTH REGION



- **ExB shearing rate increases with neon, further suppressing turbulence:**

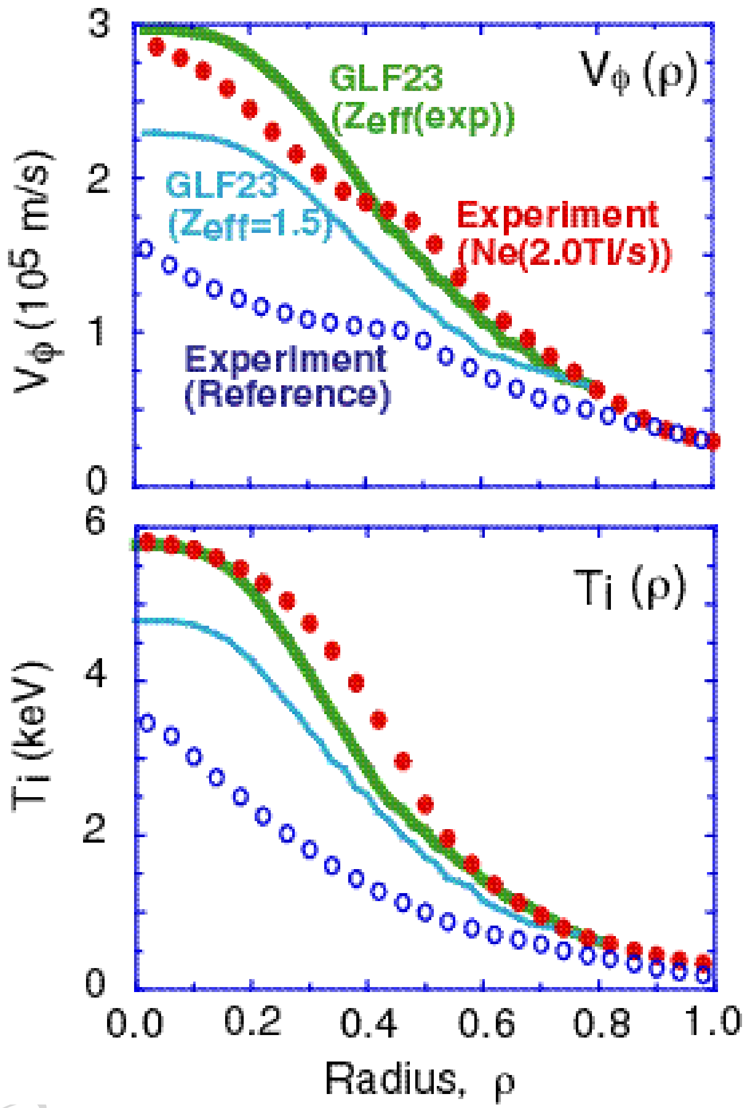
  $\frac{\gamma_{lin}}{\omega_{ExB}} \approx$ **2.5 i/2**

- **Confirmed by the FULL code with E_r** **[G. Rewoldt]**

  ITG/TEM growth rate reduced substantially with neon injection

  Inclusion of E_r effect completely stabilizes the instabilities

GLF23 simulation shows that both growth rate reduction and ExB shearing are needed to explain the observed confinement improvement



- GLF23 model includes both toroidal drift wave turbulence and ExB shear effects on all transport coefficients
- GLF23 simulation to solve V_φ, T_i, and T_e equations self-consistently to the equilibrium with the fixed experimental $n_e(\rho)$ and boundary conditions at ρ=0.8
- Two simulations are shown:

  Experimental $Z_{eff}(\rho)$

  Z_{eff} = 1.5 with carbon

Waltz et al: Plasma Phys. 97

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CONCLUSIONS

- **Significant confinement improvements are observed with impurity (Ne, Ar, Kr) into L-mode edge plasmas -- Robust and reproducible:**

  Higher stored energy by factor of 2

  Higher and broader T_i and T_e profiles

  Higher and more peaked density profiles

- **Neon produces strongest effect in the plasma, compared with Ar, Kr**
- **Reduction of turbulence is correlated well with the confinement improvement**
- **Improvements with impurity injection are observed in all transport channels:**

  Ion thermal channel -- most significant

  Electron channel -- modest

- **Both gyro-kinetic analysis and simulations indicate that the transport reductions are due to both:**

  Reduction of low-k (ion) turbulence as a result of impurity density gradient effects on main ion turbulence

  ExB shear suppression

FUTURE DIRECTIONS

Exploit impurity injection as AT tool

Test theory-based models (ITB dynamics)