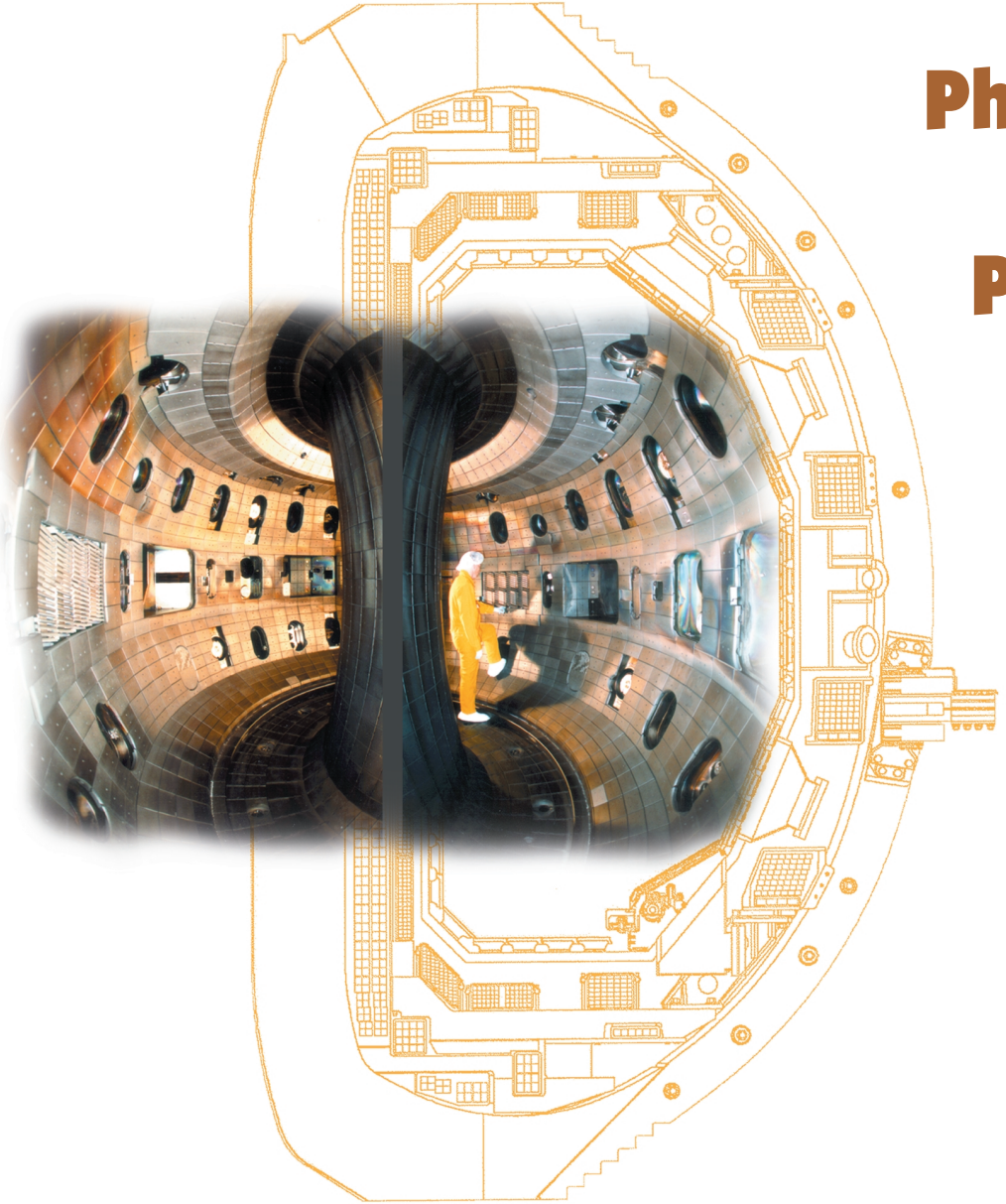

Physics of Confinement Improvement of Plasmas with Impurity Injection in DIII–D

Presented by
M. Murakami

18th IAEA
Fusion Energy Conference
Sorrento, Italy

October 7, 2000

DIII–D
NATIONAL FUSION FACILITY

IAEA-CN-77/EX5/1

Physics of Confinement Improvement of Plasmas with Impurity Injection in DIII–D

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INTRODUCTION

- **Confinement improvement in discharges with impurity seeding have been observed in a number of tokamaks:**
  - **ISX-B (Z-mode)**
  - **TEXTOR-94 (RI-mode)**
  - **TFTR, ASDEX, DIII-D, JET, ...**
- **In the present DIII-D experiment, injection of noble gas (Ne,Ar, Kr) into L-mode edge discharges has produced:**
  - **Clear confinement improvement ($\times$2)**
  - **Transport reduction in all transport channels (χ_i by $\times$5)**
  - **Simultaneous reduction in long-wavelength turbulence**
- **These observations provide opportunities to test understanding of theory-based transport models**
  - **Gyro-kinetic analysis**

    $\Rightarrow$ Synergistic effects of impurity-induced reduction of toroidal drift wave turbulence and ExB shearing suppression
  - **Theory-based transport modeling (GLF23)**
- **Impurity seeding is also a useful tool for:**
  - **Reduction of heat flux to plasma facing components**
  - **L-mode edge with improved confinement**
  - **Internal Transport Barrier control** – [E. Doyle: EX6/2]
  - **H-mode edge stability control**

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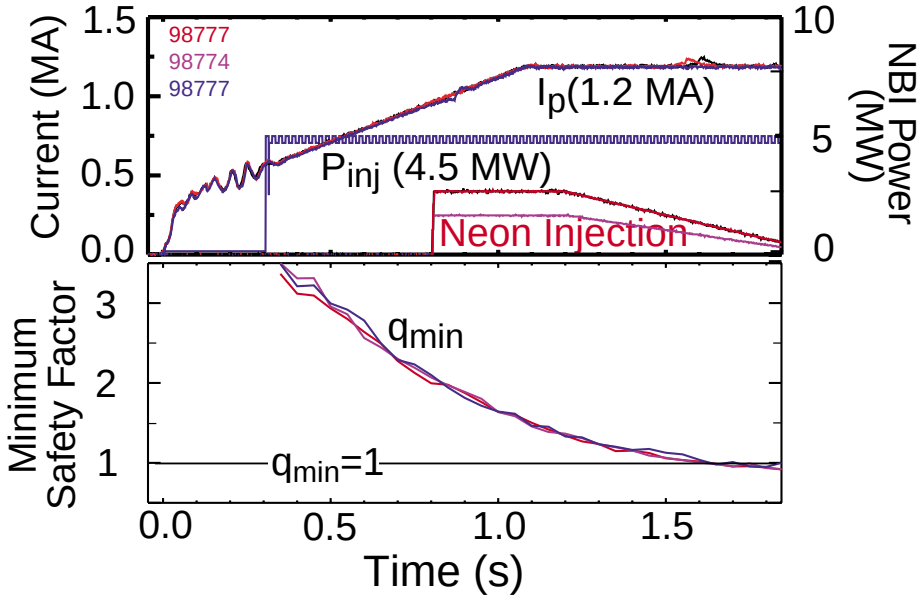
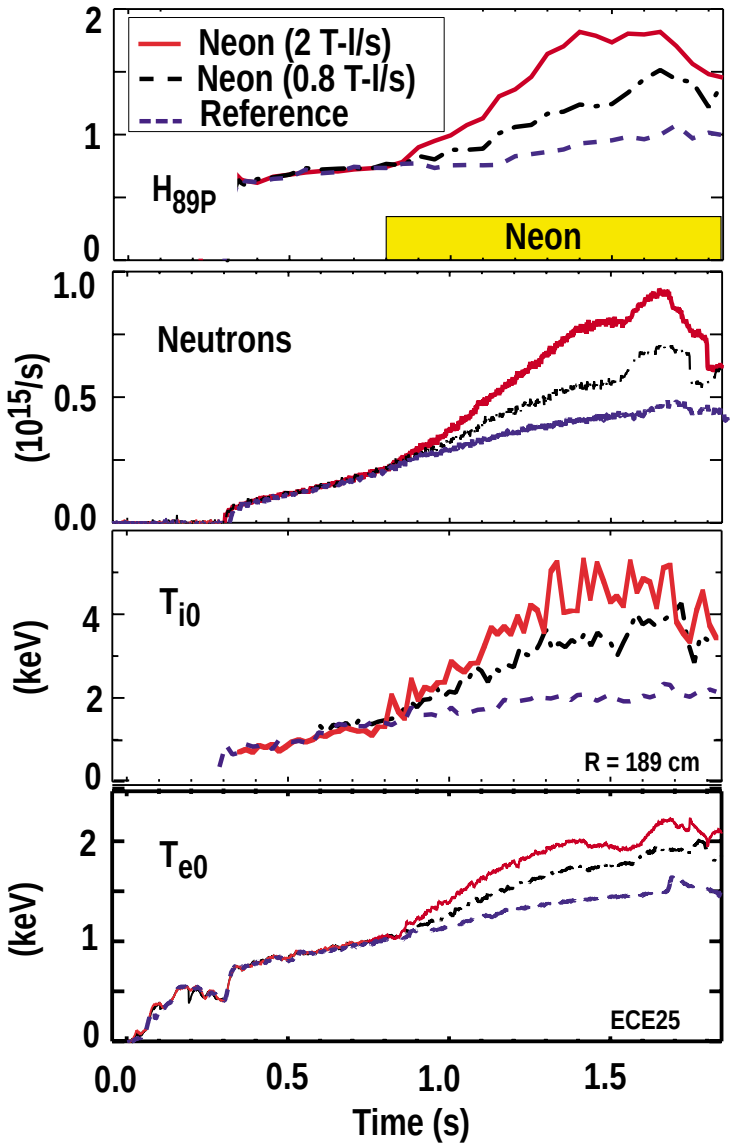
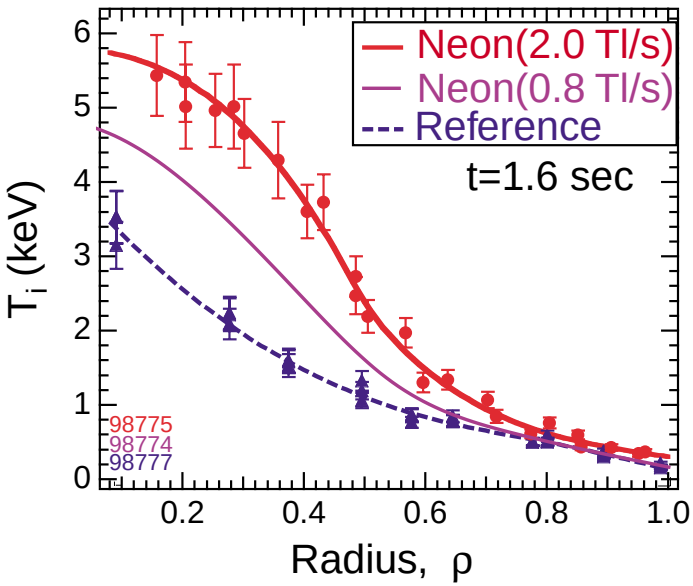
IMPURITY INJECTION SIGNIFICANTLY IMPROVES CONFINEMENT PARAMETERS

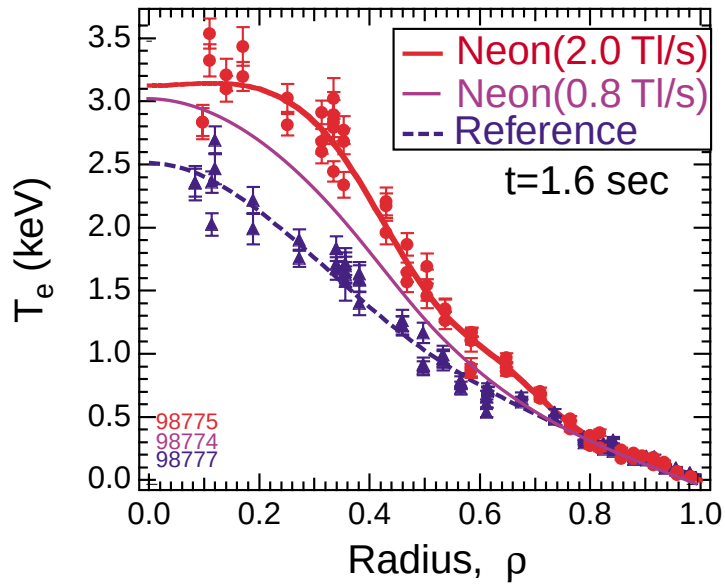


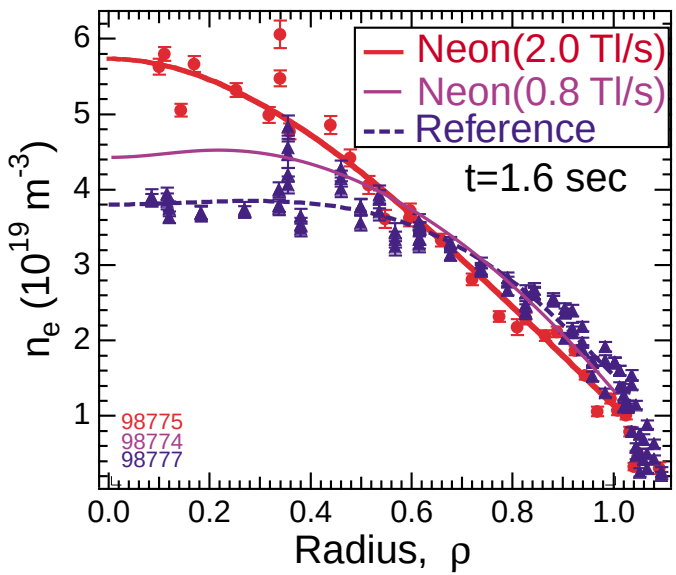
- USN with L-mode edge
- Early NBI ⇒ q_{min}>1 to avoid sawtooth
- Ne, Ar, Kr (recycling gas) injected at 0.8 s and 1.2 s, quantity varied
- Run reference discharges with similar control parameters except no impurity puffed

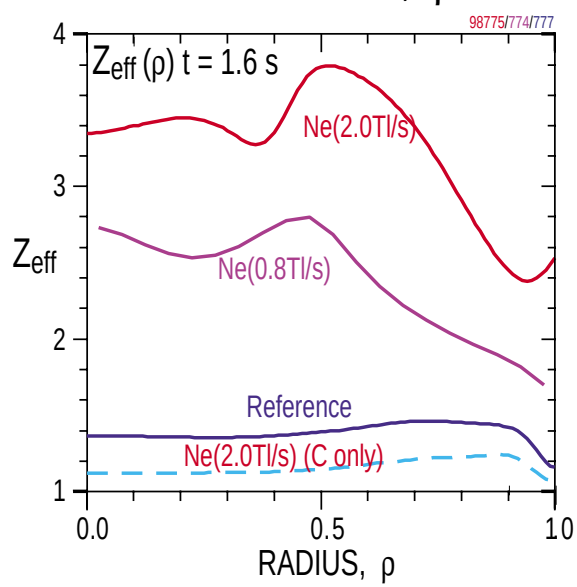


NEON INJECTION PRODUCES HIGHER AND BROADER T_i AND T_e PROFILES, AND MORE PEAKED DENSITY PROFILES









- **Density peaking factor: $n_e(0)/\langle n_e \rangle$ = 1.2 ⇒ 1.5**
- **Charge Exchange Recombination spectroscopy, showing n_{Ne}/n_e < 2.2%**

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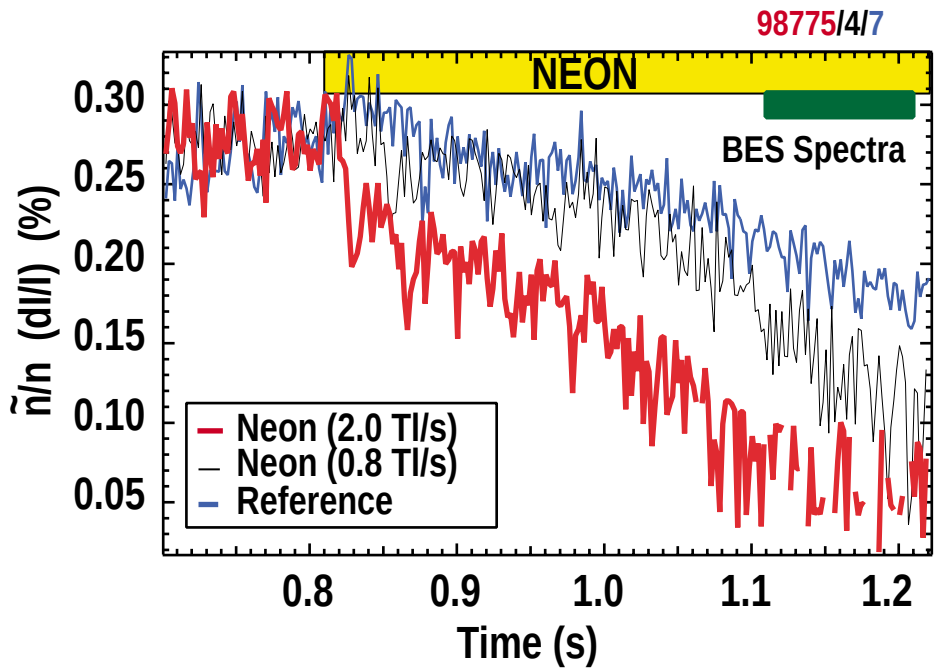
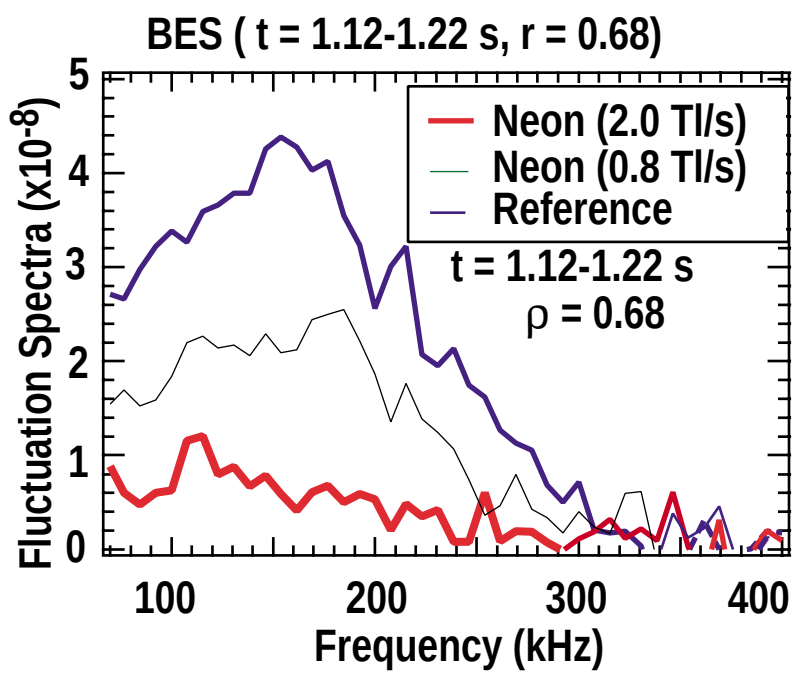
CONFINEMENT IMPROVEMENT IS CORRELATED WITH STRONG REDUCTION OF TURBULENCE WITH IMPURITY INJECTION

- BES measures density fluctuations ($k_\theta \rho_s < 0.6$) at $\rho = 0.68$





- Reduction of turbulence is also observed by FIR scattering
- Reciprocating probe observed reduction of particle flux $\Gamma \sim \langle \tilde{n}\tilde{\phi} \rangle$ at edge

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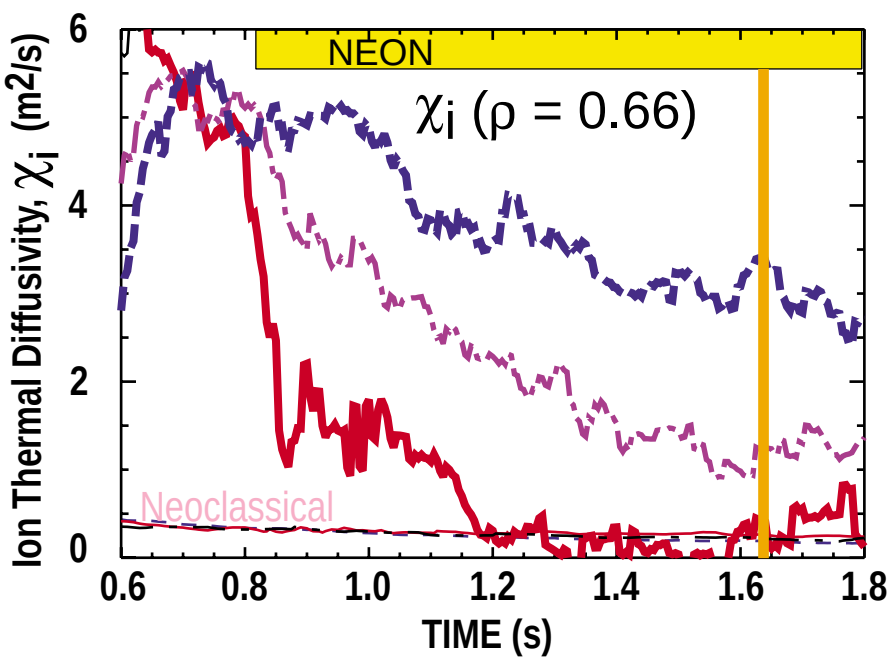
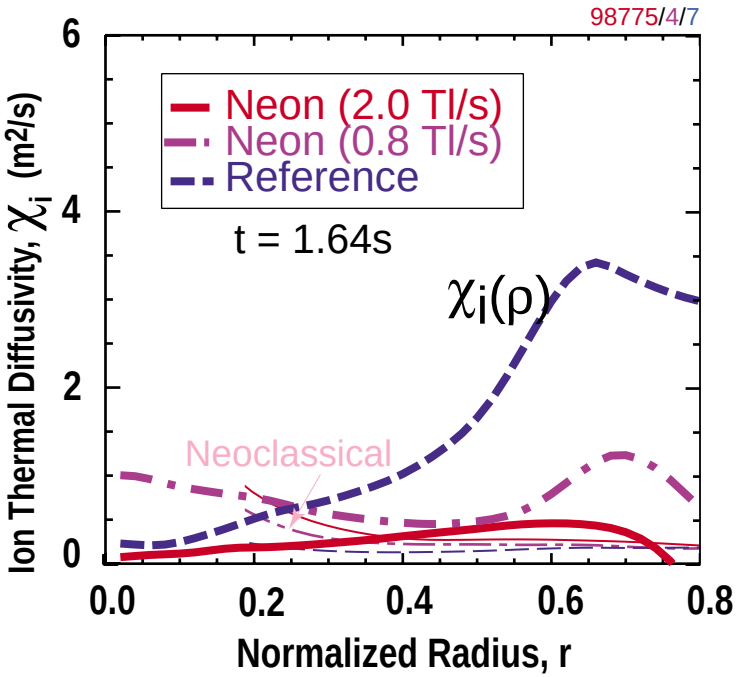
TRANSP ANALYSIS SHOWS THAT ION THERMAL DIFFUSIVITY DECREASES STRONGLY WITH NEON INJECTION





- $\chi_i(\rho)$ is reduced throughout the profile to the neoclassical level

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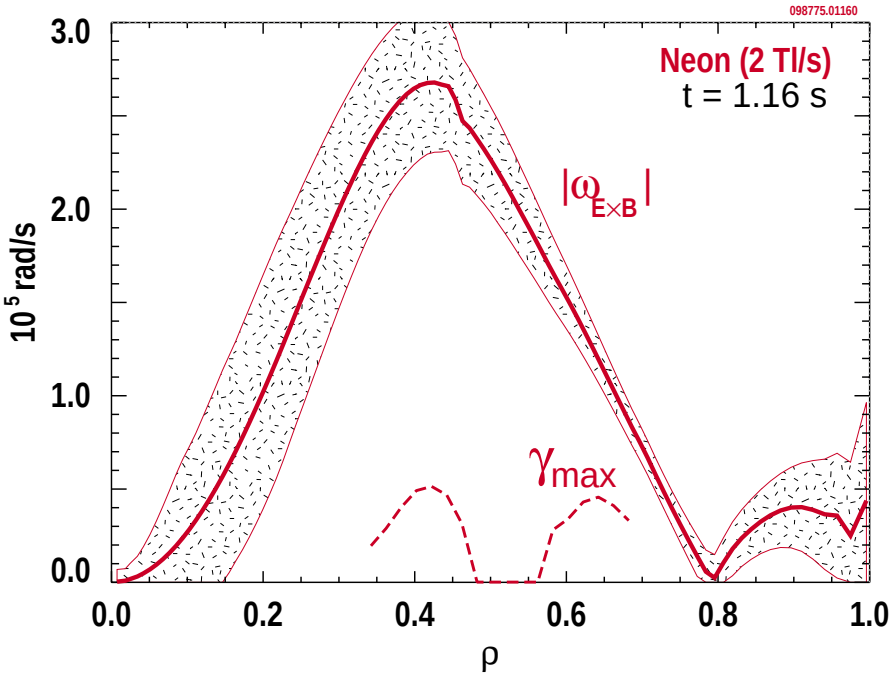
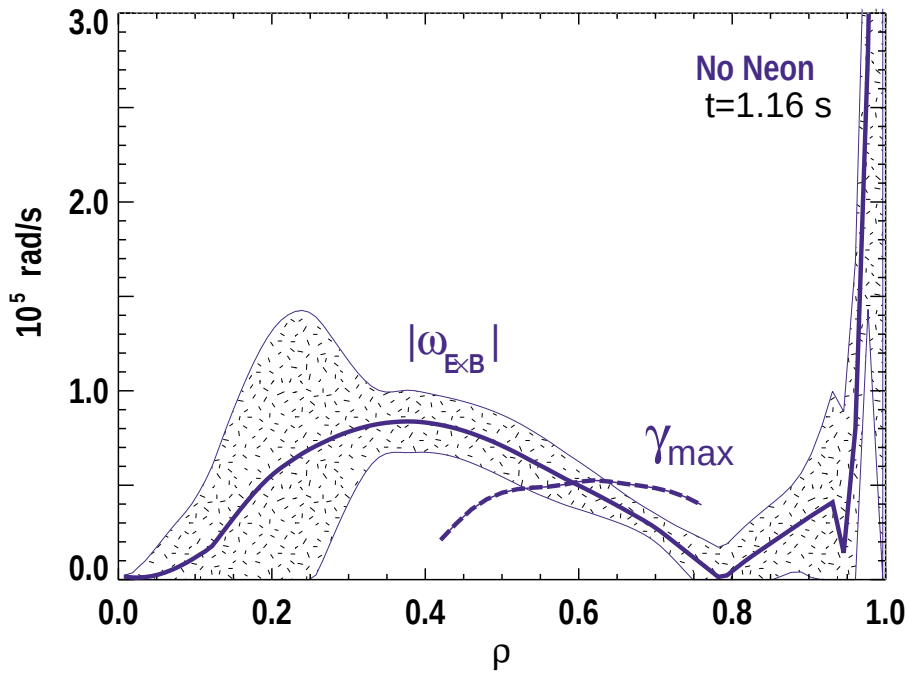
NEON INJECTION REDUCES TURBULENCE GROWTH RATES AND INCREASES ExB SHEARING RATE





- Gyro-Kinetic Stability (GKS) code is used to calculate linear growth rates based on experimental profiles

⇒ Growth rates (primarily ITG) reduced by main ion dilution, direct mode stabilization with impurities and profile effects

- ExB shearing rate is calculated from radial electric field based on measured V_ϕ, V_θ, and p_i of carbon impurity
- Criteria for stabilization: $|\omega_{ExB}| > \gamma_{max}$

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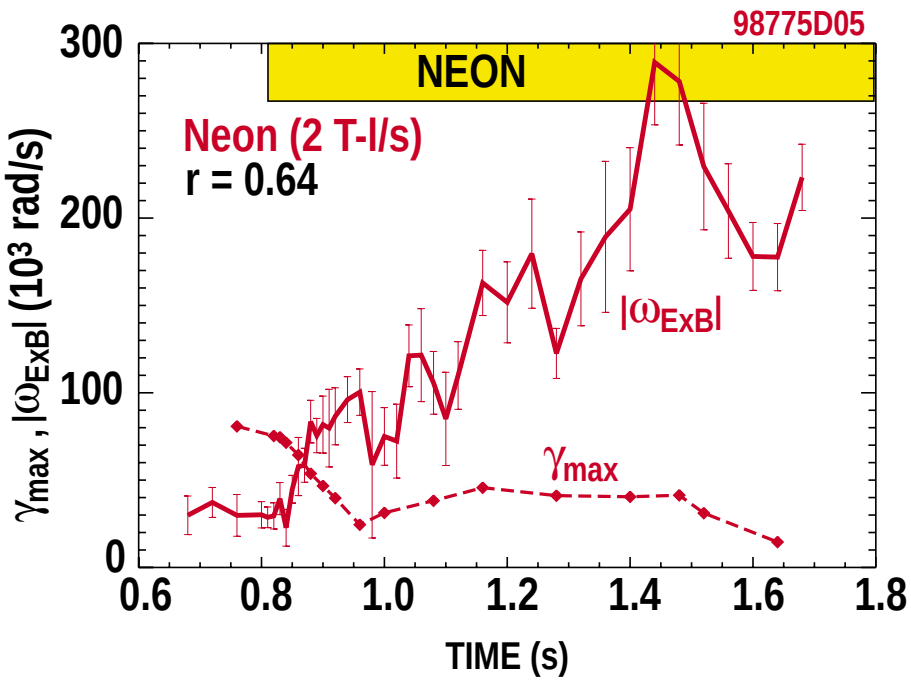
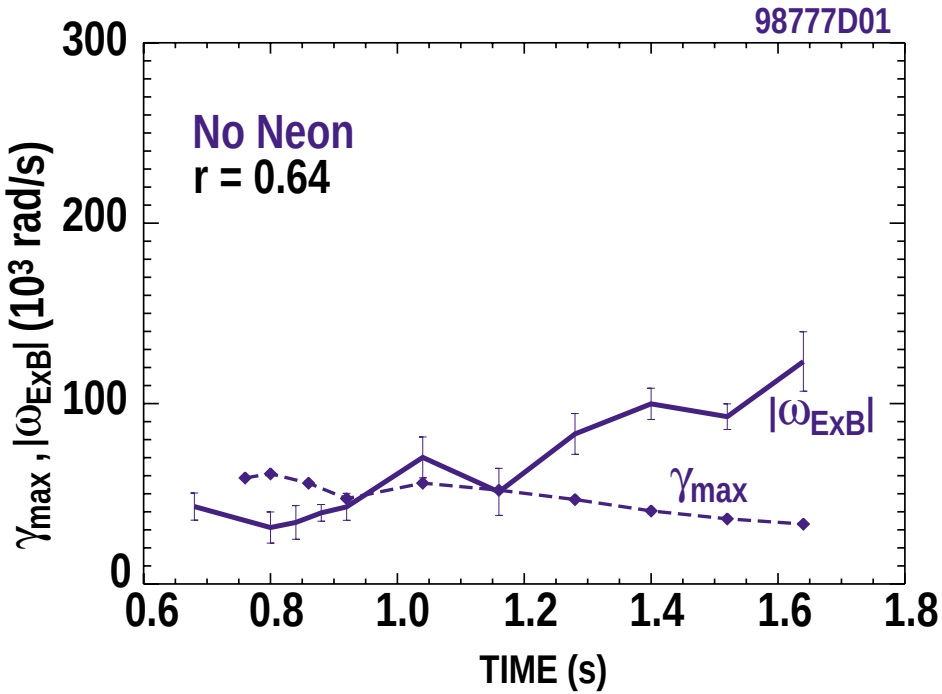
NEON INJECTION TRIGGERS THE PROCESS OF CONTINUOUS RISE IN THE ExB SHEARING RATE WHILE THE MAXIMUM GROWTH RATE IS REDUCED





- The initial drop in γ_{max} triggers the rise of ω_{ExB} with neon injection
- ExB shear suppression is clearly established in the latter phase

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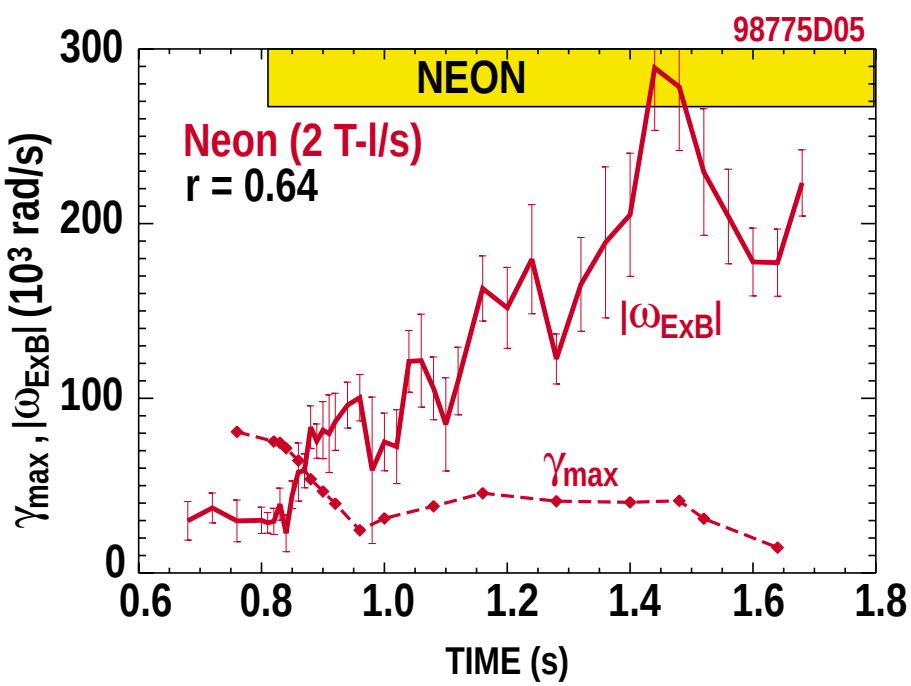
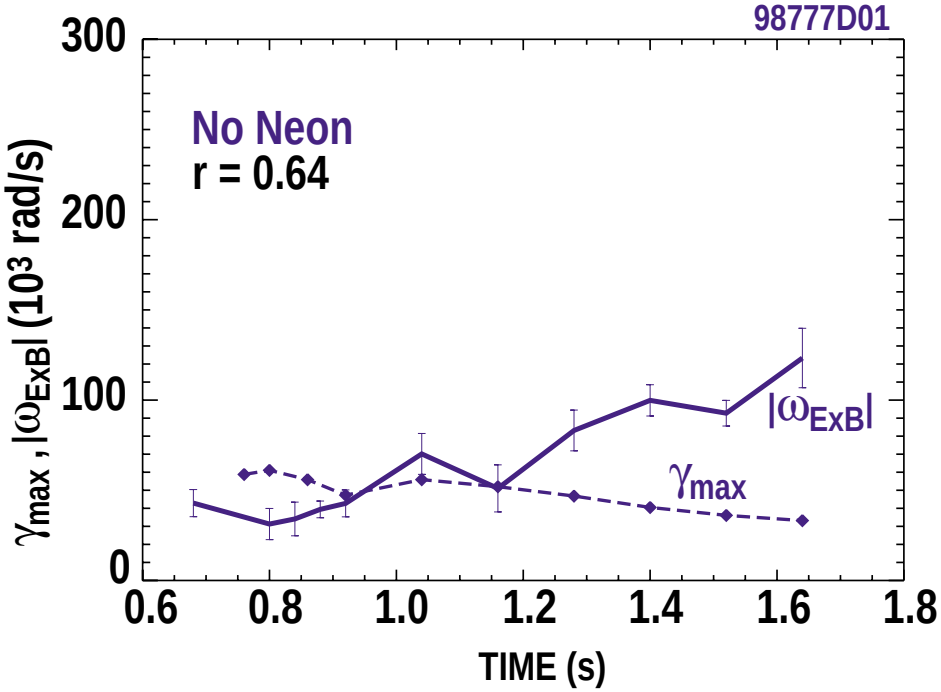
NEON INJECTION REDUCES TURBULENCE GROWTH RATES AND INCREASES ExB SHEARING RATE





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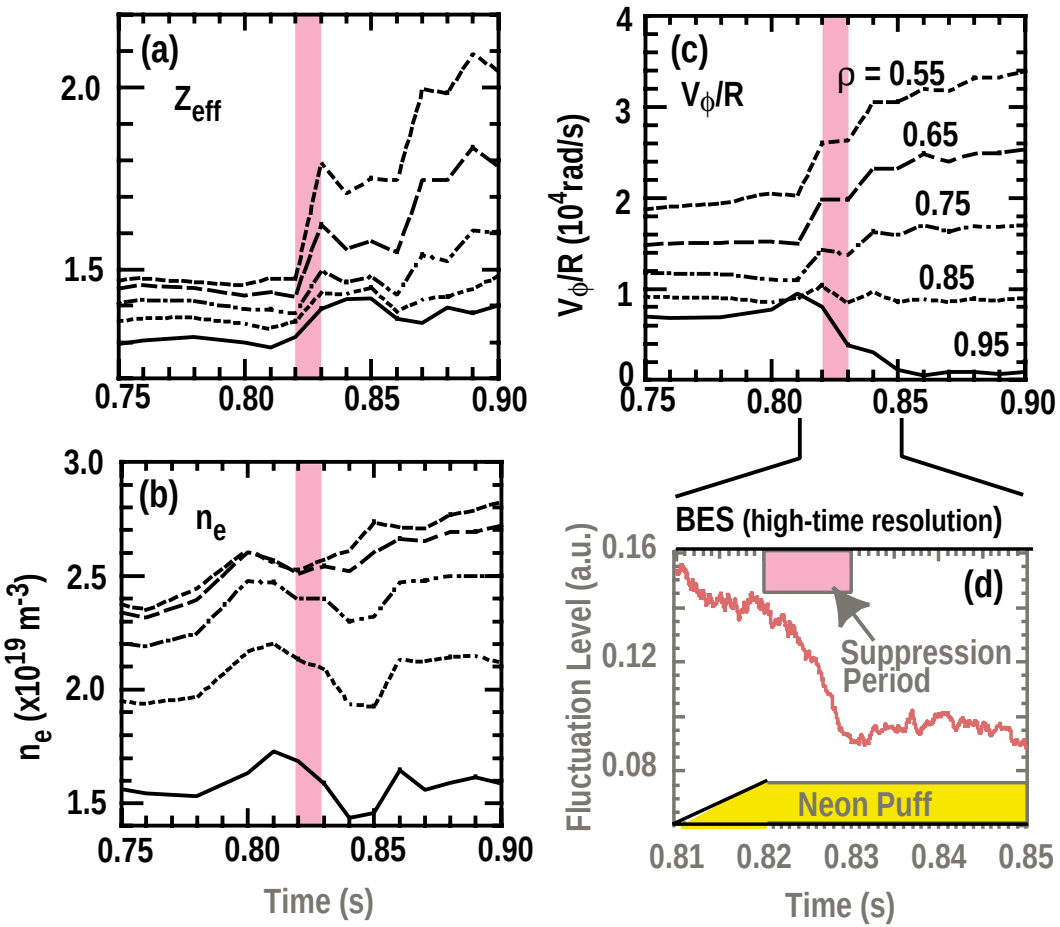
PROMPT LOCAL TRANSPORT REDUCTION AND LOW-k TURBULENCE SUPPRESSION RESULTS FROM AN INCREASING ROTATION GRADIENT ENHANCING THE ExB SHEARING



- Some density peaking ⇒ Only modest effect on γ_{max}
- Rapid change in V_ϕ ⇒ Increase in ∇V_ϕ ⇒ Increase in ω_{ExB}
  ⇒ reduce low-k fluctuations

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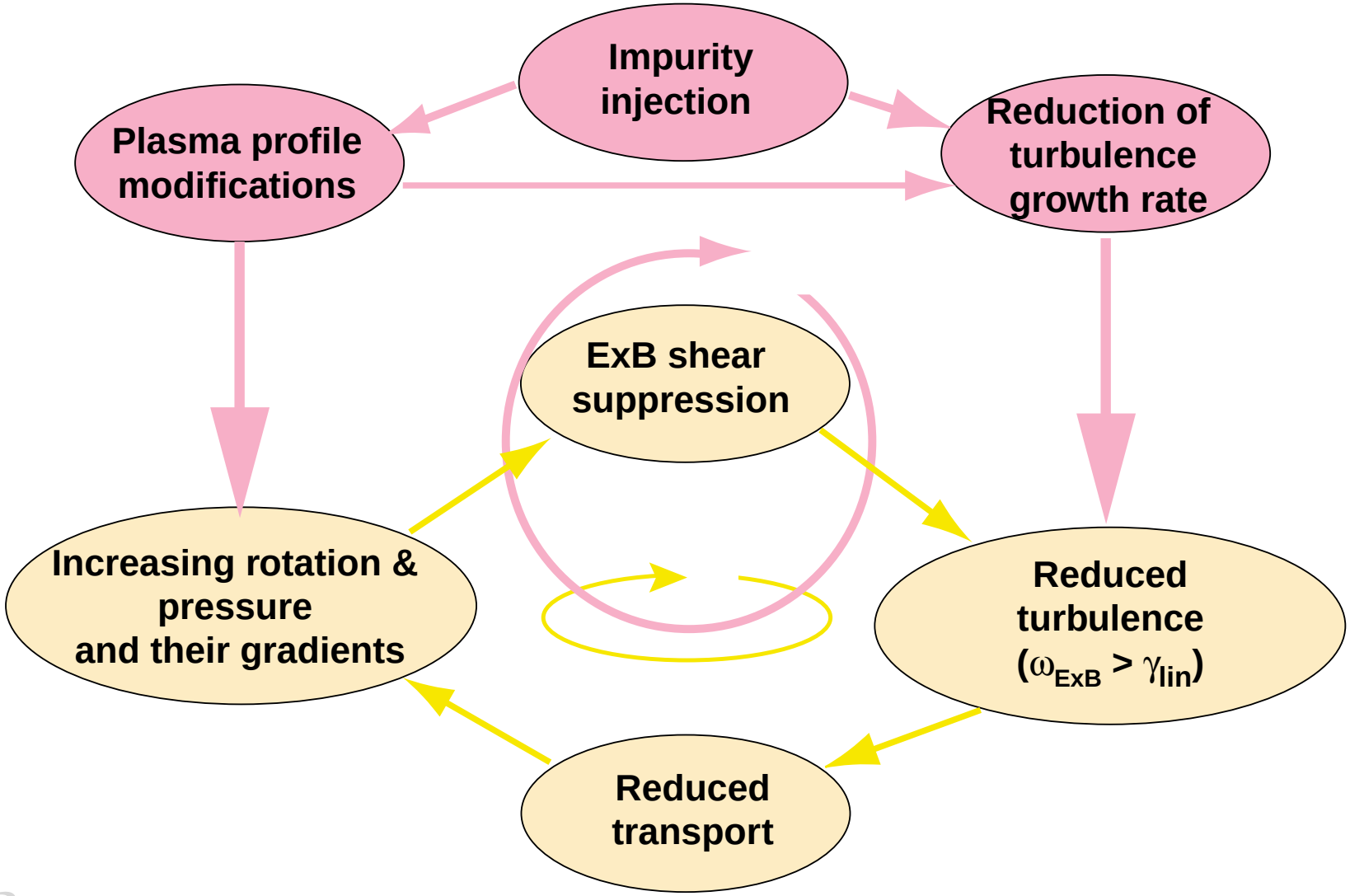
DIRECT IMPURITY EFFECTS ACT SYNERGISTICALLY WITH THE ExB SHEARING SUPPRESSION



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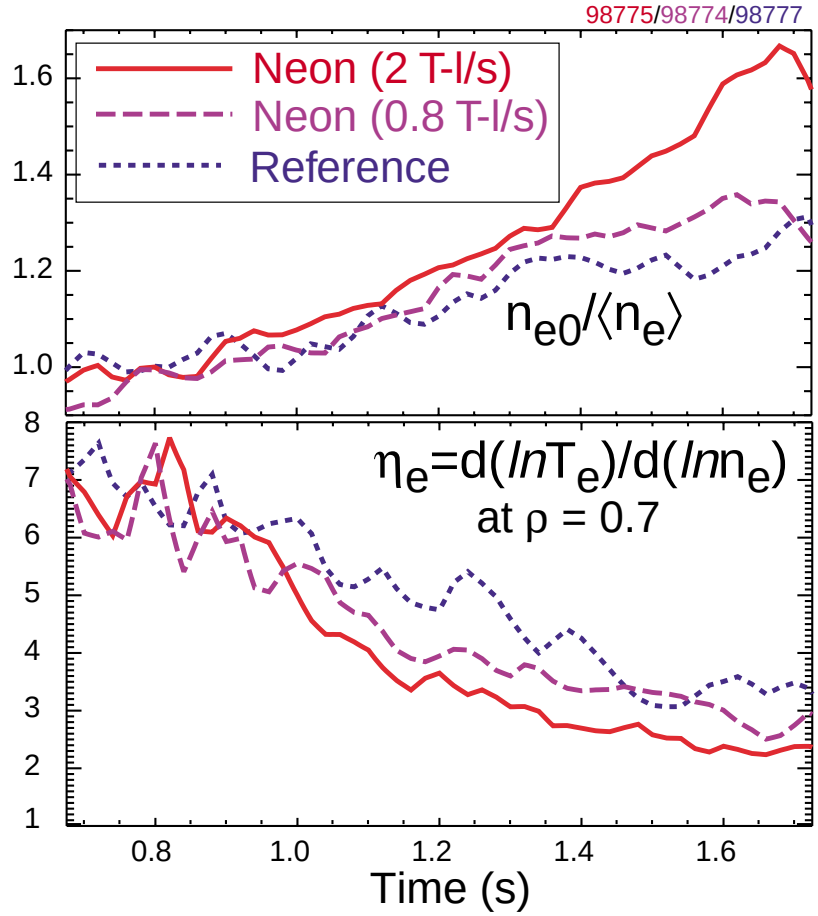
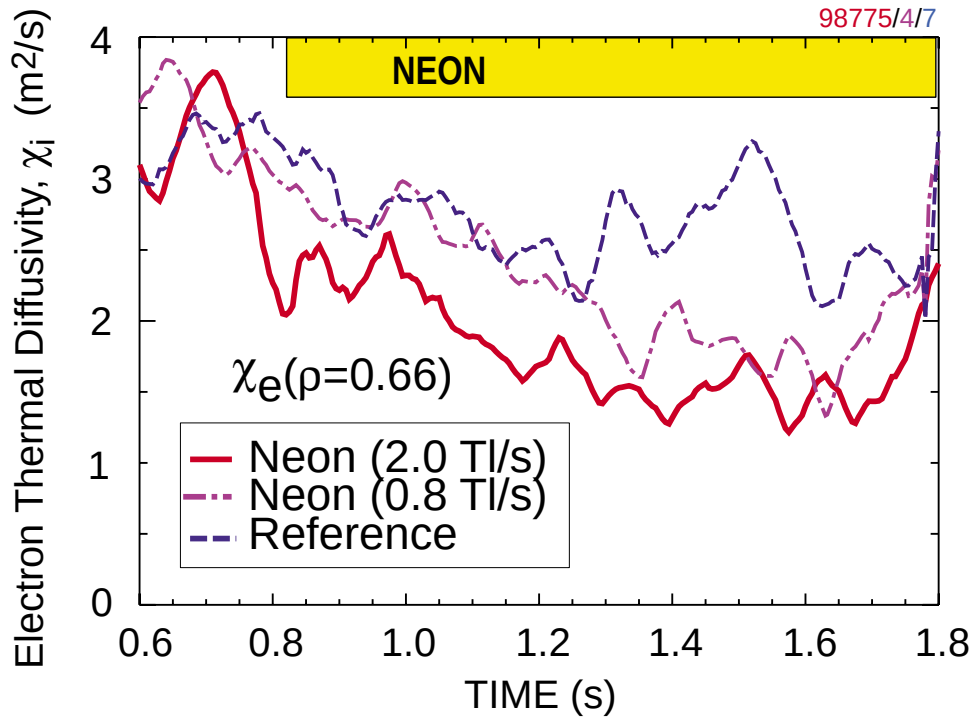
PLASMA PROFILES ALSO EVOLVE, HELPING TURBULENCE STABILIZATION





- **Can we separate these three effects?**
  - **Direct impurity effects for γ_{max}**
  - **ExB shear suppression**
  - **Other profile evolutions**

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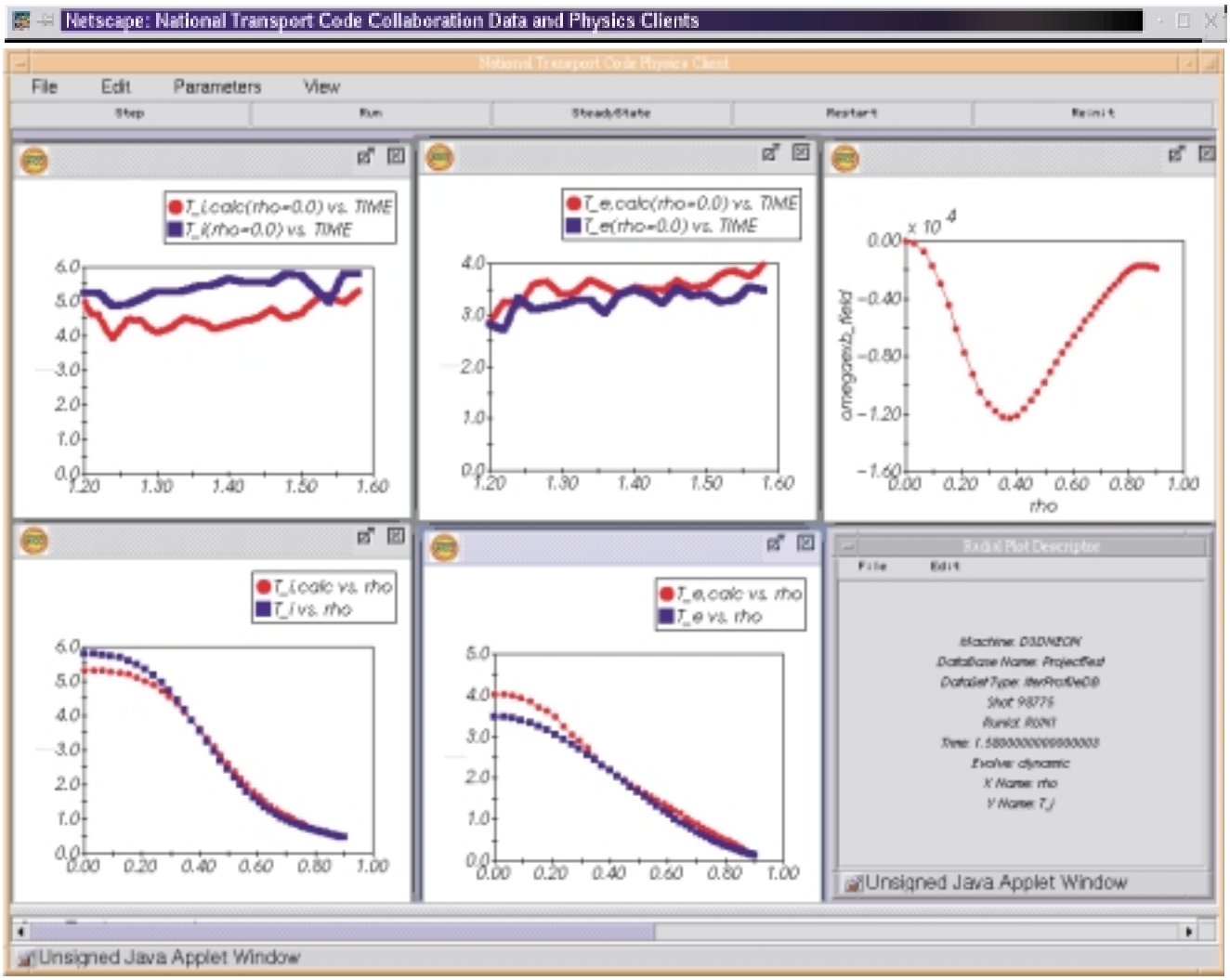
ROLES OF DIRECT IMPURITY EFFECTS AND ExB SHEAR SUPPRESSION ARE EXPLORED WITH A THEORY-BASED TRANSPORT MODEL



- Gyro-Landau Fluid (GLF23) model allows to study both effects on transport
  [R. Waltz et al.: Phys. Plasmas '97]
- The GLF23 model was carried out using a time-dependent transport code, NTCC Demonstration Code
- The National Transport Code Collaboration (NTCC) project is to develop:
  - Library of transport code modules
  - Web-invokable data server and demonstration code
- DIII-D Neon shots have been selected as the principal test case for the NTCC Demonstration Code
- The code solves T_i and T_e equations with inputs of:
  - $n_e(\rho,t)$ and $V_\phi(\rho.t)$
  - Time-dependent sources, sinks and equilibria from TRANSP

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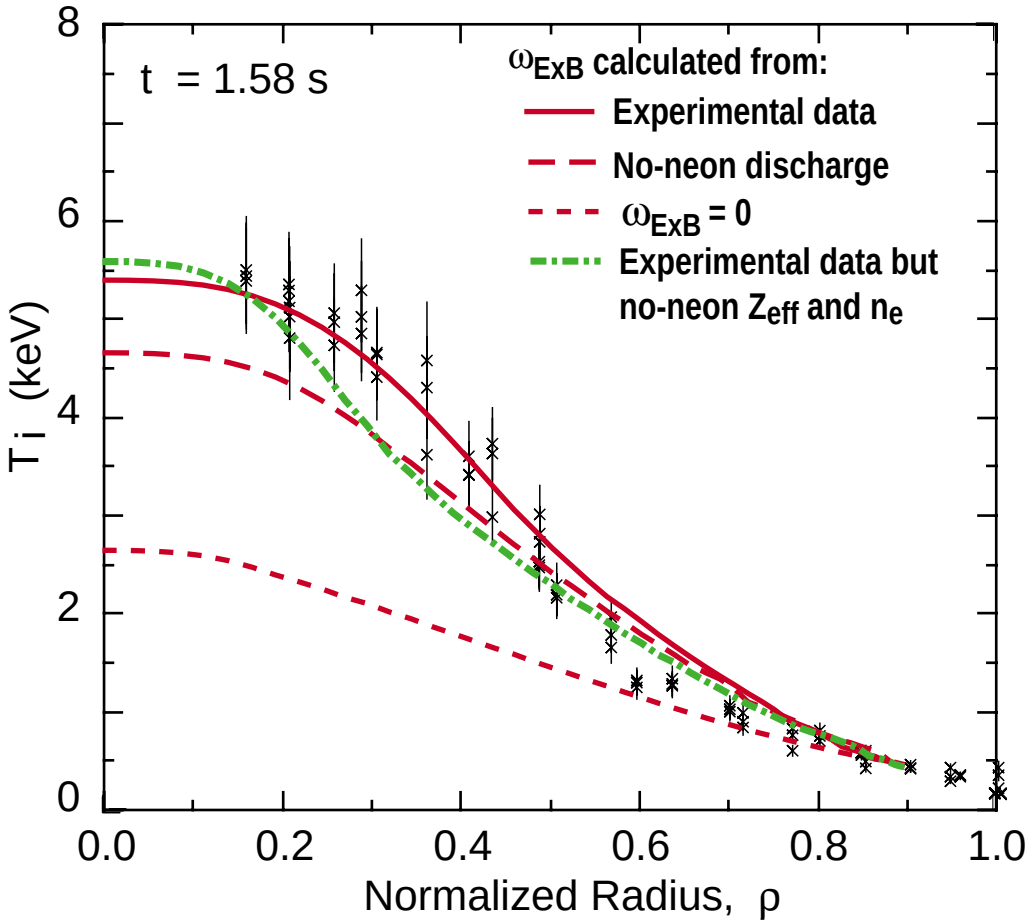
NTCC NATIONAL TRANSPORT CODE COLLABORATION

INCREASE IN ExB SHEARING RATE IS A NECESSARY CONDITION FOR CONFINEMENT IMPROVEMENT



Simulations are used to test:

- Effects of ExB shearing from experimental ω_{ExB} to 0
- Effects of changing Z_{eff} (3.2 $\rightarrow$ 1.4) and $n_e(\rho)$ after the improved state is established

$\Rightarrow$ Neon injection may be used as a trigger

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NICC NATIONAL TRANSPORT CODE COLLABORATION

CONCLUSIONS

- External impurity injection in L–mode edge discharges in DIII–D produced:
  - Clear confinement improvement ($\times 2$ in τ_E, and S_n)
  - Reduction in all transport channels (χ_i to neoclassical)
  - Simultaneous reduction of long-wavelength turbulence

- Reduction in fluctuations and ion thermal transport is attributed to two impurity-induced effects working synergistically: reduction of toroidal drift wave turbulence and ExB shear suppression

- Impurity injection is observed to trigger reduction of long-wavelength turbulence by increasing the gradient of toroidal rotation which enhances ExB flow shear

- Time-dependent simulations with GLF23 model show the dominant role of ExB shearing and a possibility of using impurity injection as a trigger
  - Remove impurity source after obtaining confinement improvement

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