Poster: GP1.119

MECHANISMS FOR REDUCTION OF ION TRANSPORT AND TURBULENCE 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 (×2)
  - Transport reduction in all transport channels (χ_i by ×5)
  - Simultaneous reduction in long-wavelength turbulence
- These observations provide opportunities to test understanding of theory-based transport models
  - Gyro-kinetic analysis
    - ⇒ 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
  - H-mode edge stability control

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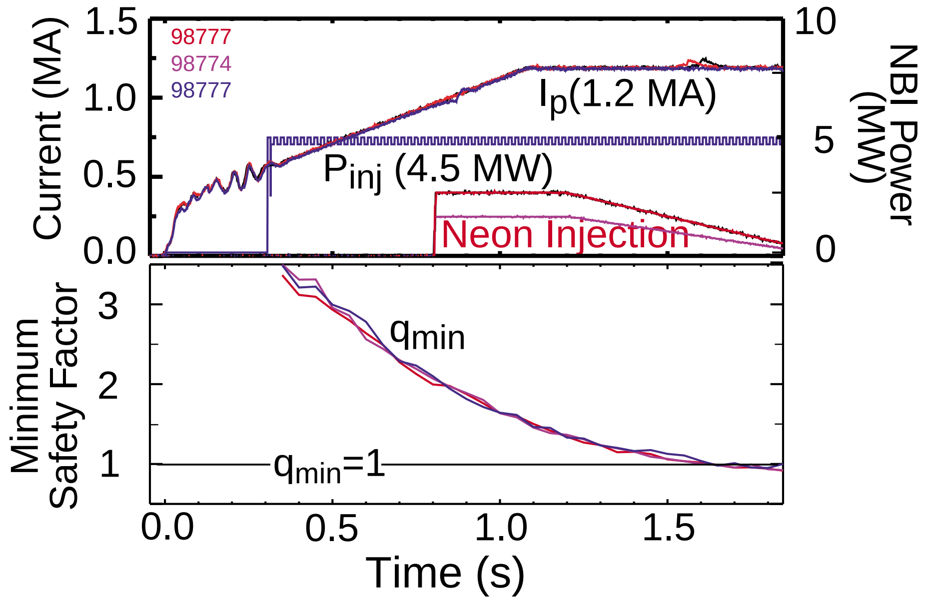
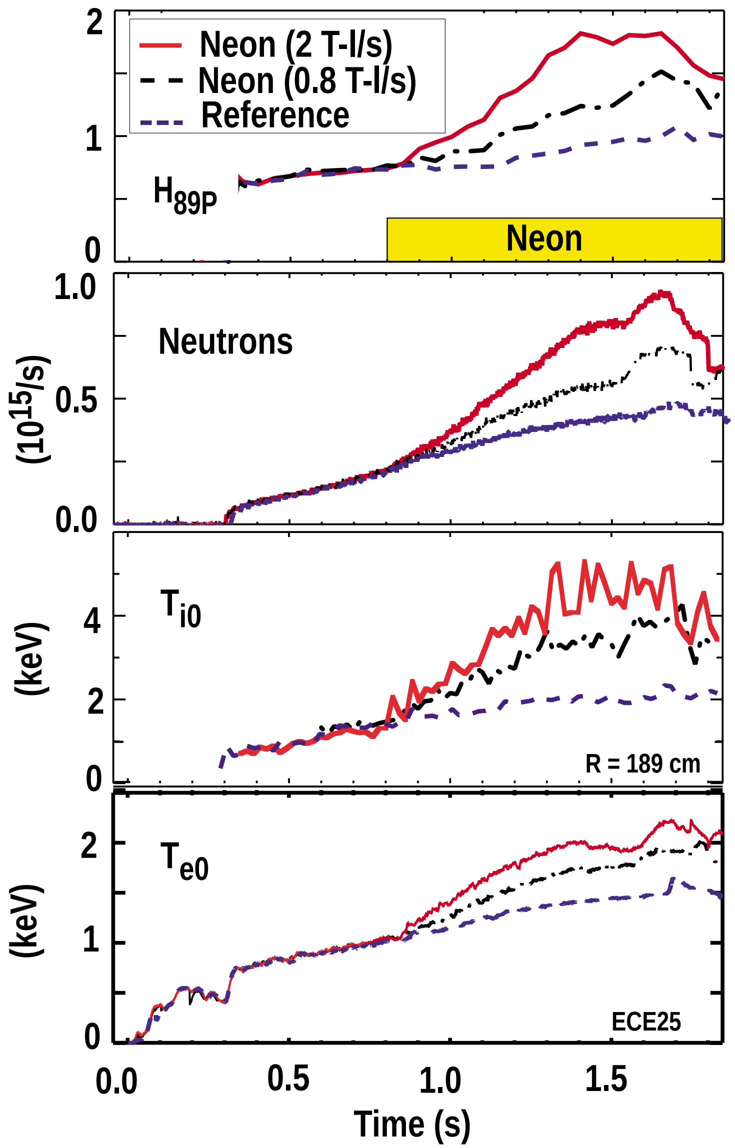
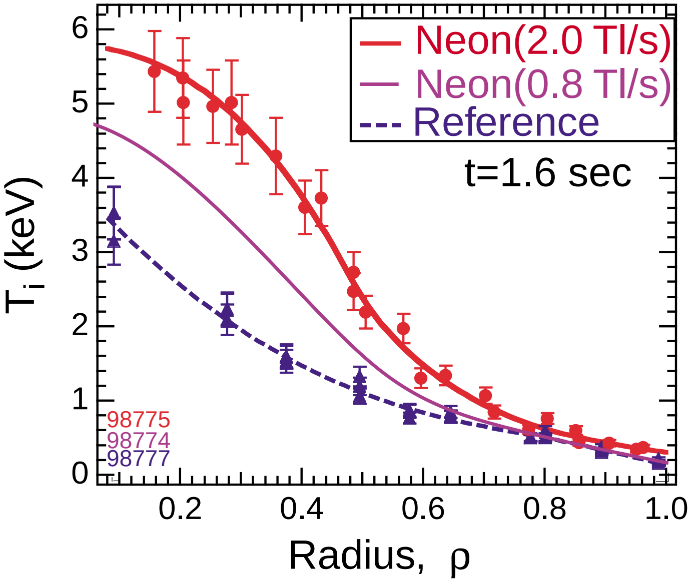
IMPURITY INJECTION SIGNIFICANTLY IMPROVES CONFINEMENT PARAMETERS

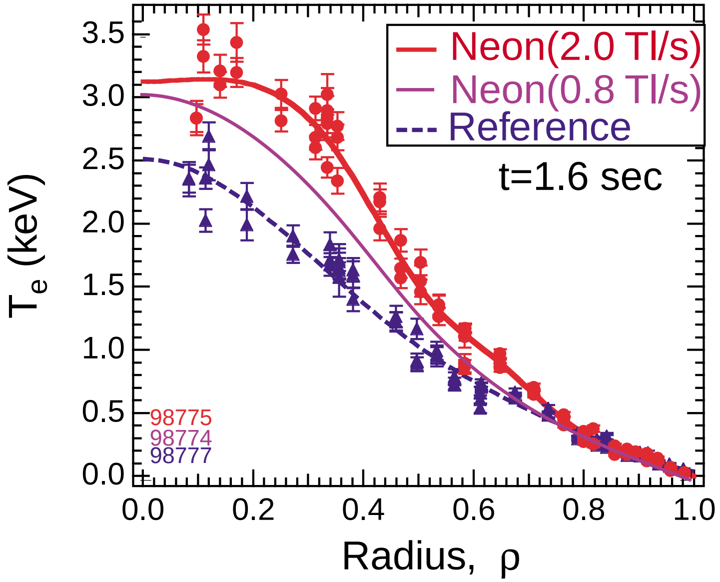


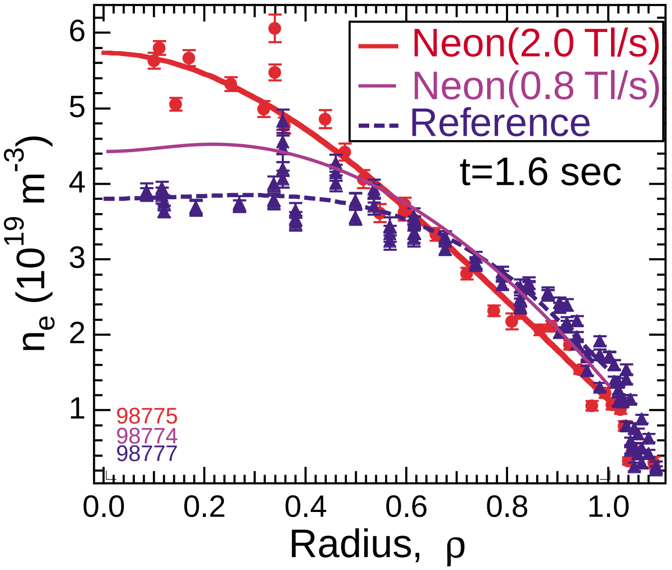


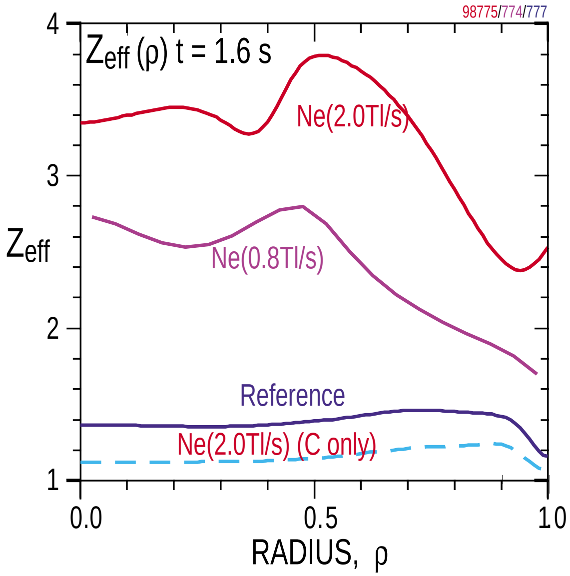
- USN with L-mode edge
- Early NBI ⇒ q_{min}>1 to avoid sawtooth
- Ne, Ar, Kr (recycling gas) injected at 0.8 s and 1.2 s, quantity varied
- Run reference discharges with similar control parameters except no impurity puffed

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









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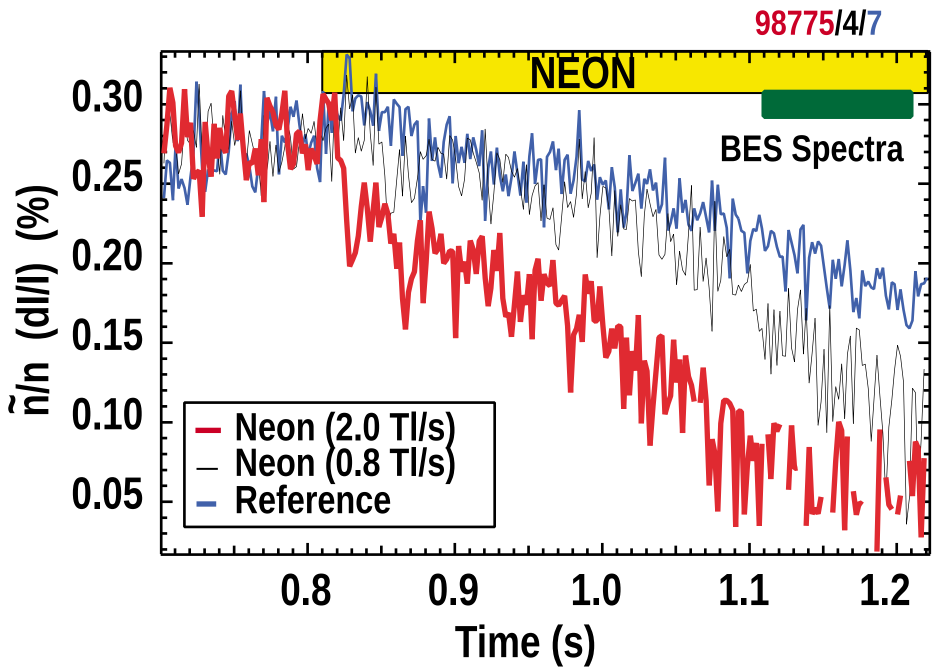
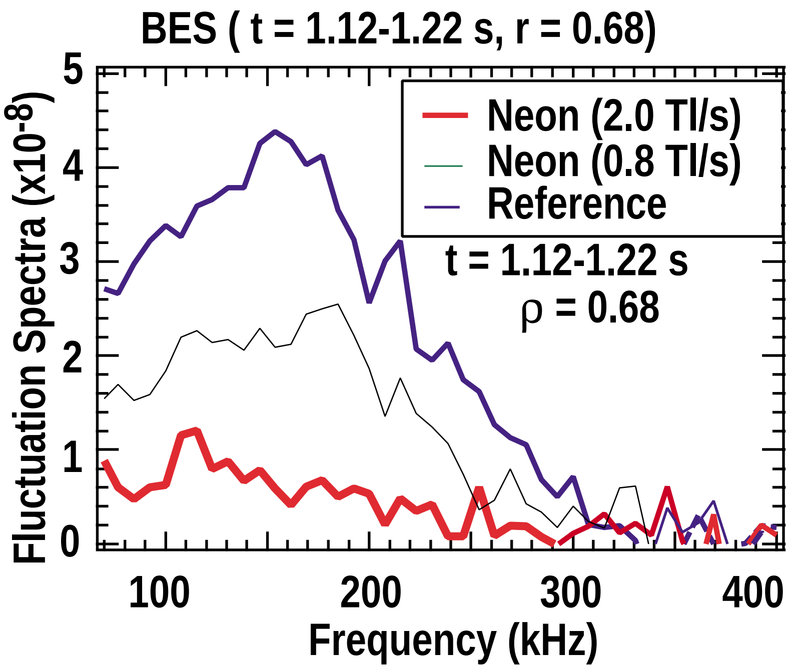
- **Density peaking factor: $n_e(0)/\langle n_e \rangle = 1.2 \Rightarrow 1.5$**
- **Charge Exchange Recombination spectroscopy, showing $n_{Ne}/n_e < 2.2\%$**

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

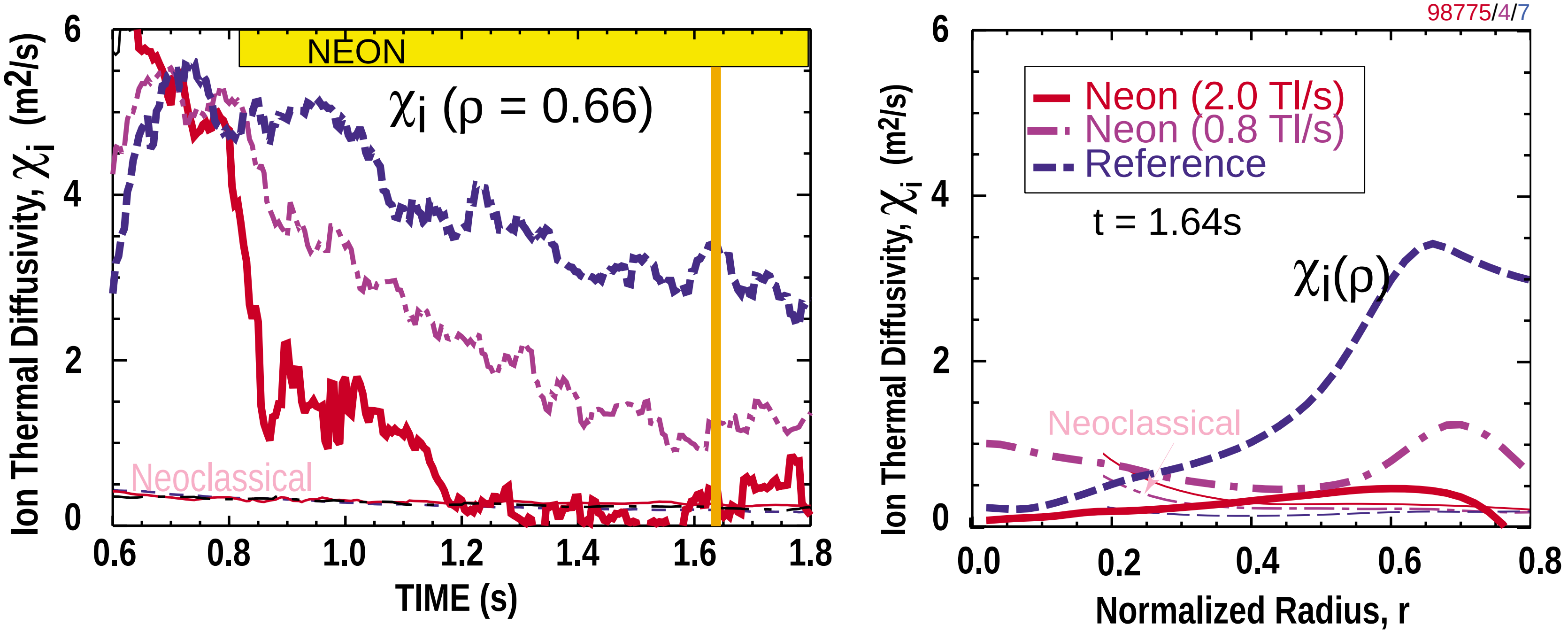
- BES measures density fluctuations ($k_\theta \rho_s < 0.6$) at $\rho = 0.68$





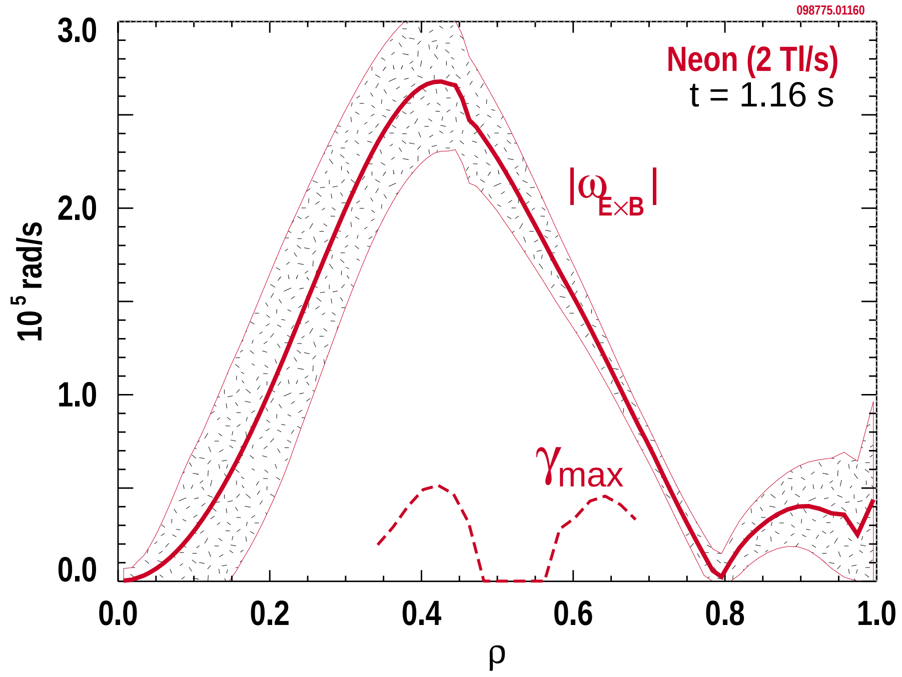
- Reduction of turbulence is also observed by FIR scattering
- Reciprocating probe observed reduction of particle flux $\Gamma \sim \langle \tilde{n}\tilde{\phi} \rangle$ at edge

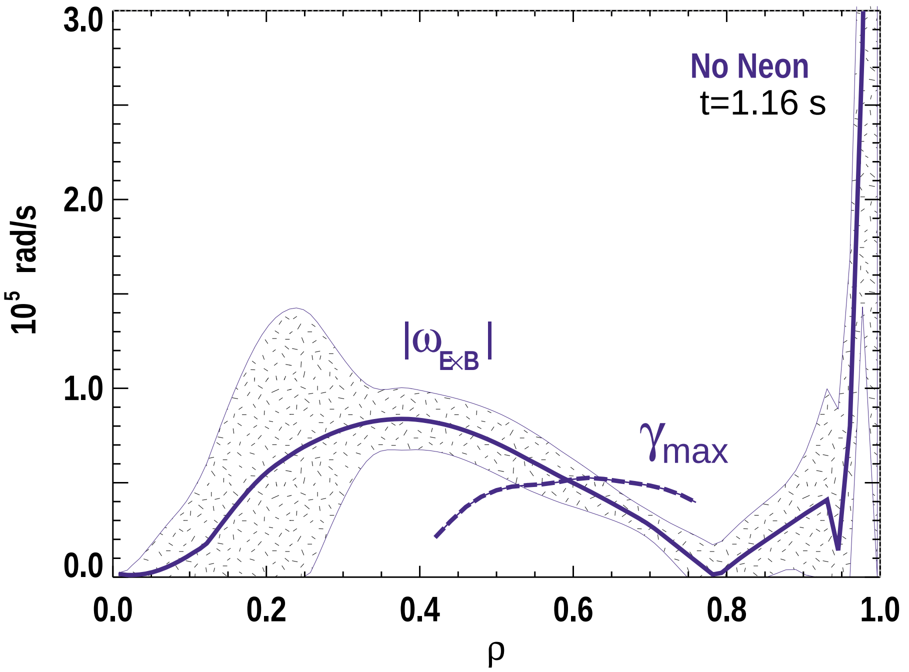
TRANSP ANALYSIS SHOWS THAT ION THERMAL DIFFUSIVITY DECREASES STRONGLY WITH NEON INJECTION



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

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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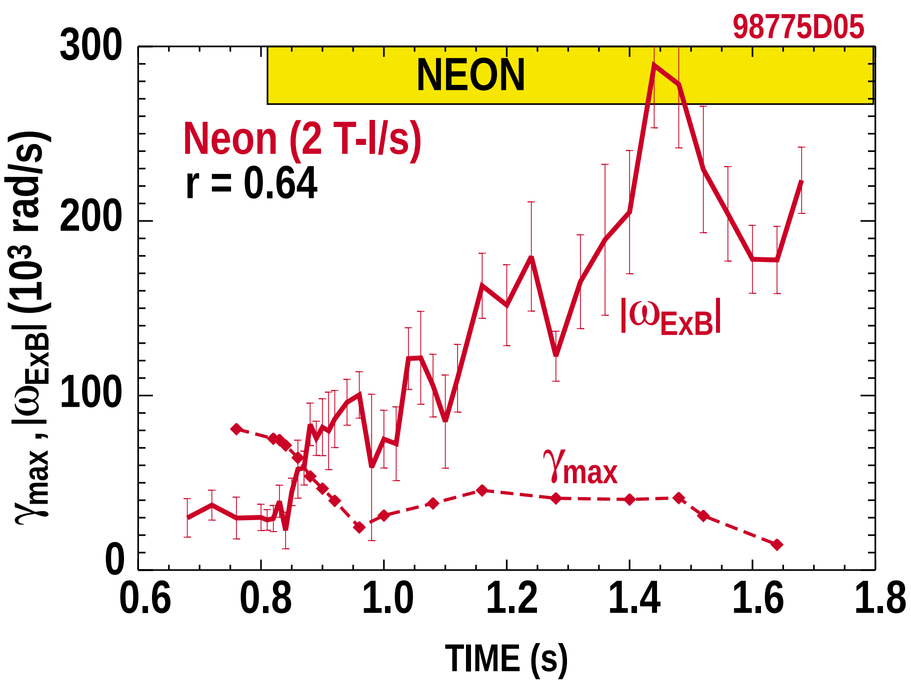

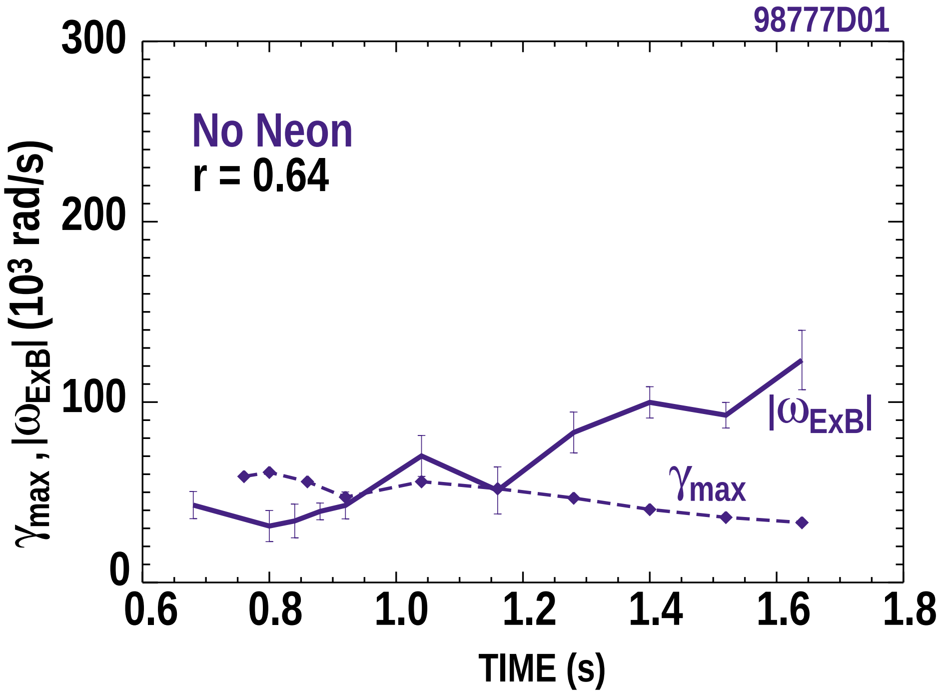

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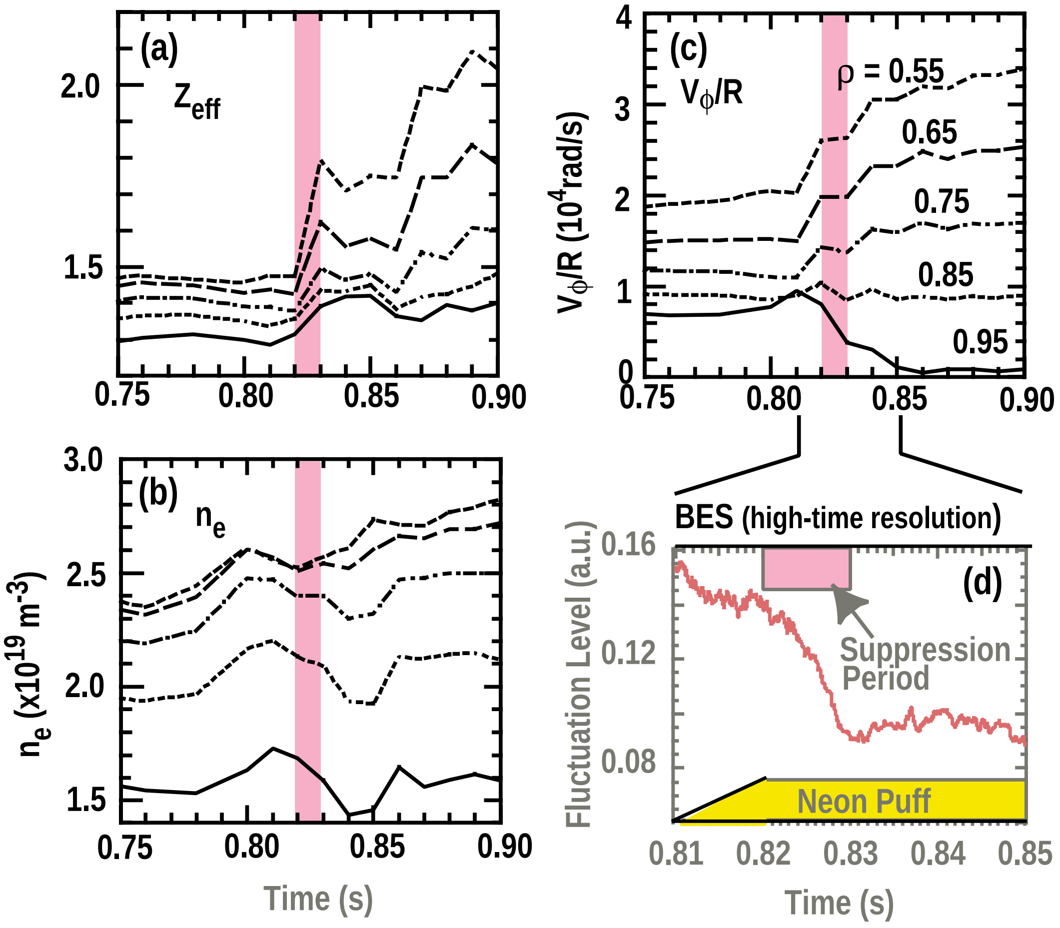
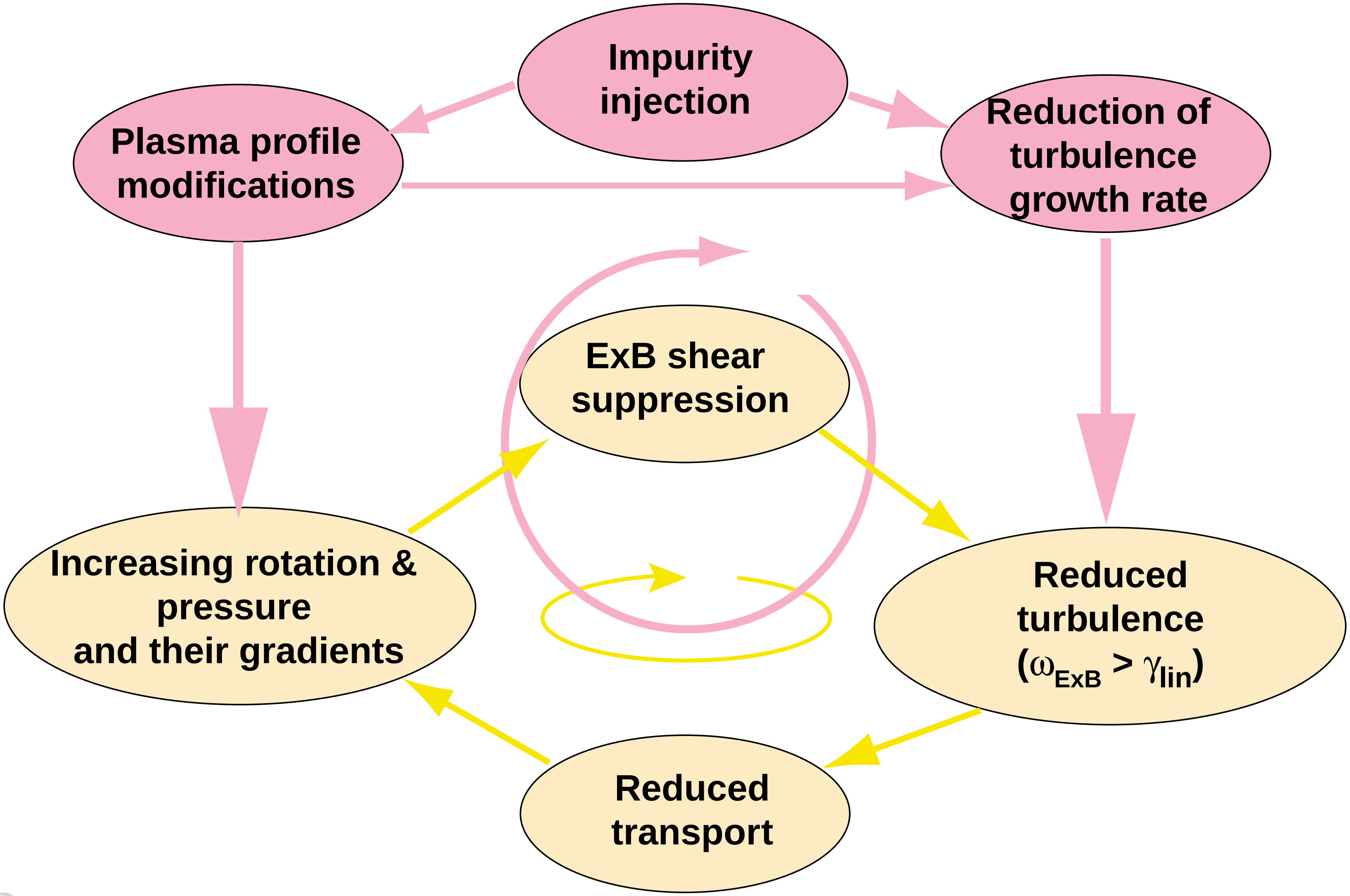
PROMPT LOCAL TRANSPORT REDUCTION AND LOW-k TURBULENCE SUPPRESSION RESULTS FROM AN INCREASING ROTATION GRADIENT ENHANCING THE ExB SHEARING



- 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

DIRECT IMPURITY EFFECTS ACT SYNERGISTICALLY WITH THE ExB SHEARING SUPPRESSION



Impurity injection

Plasma profile modifications

Reduction of turbulence growth rate

ExB shear suppression

Increasing rotation & pressure and their gradients

Reduced turbulence ($\omega_{ExB} > \gamma_{lin}$)

Reduced transport

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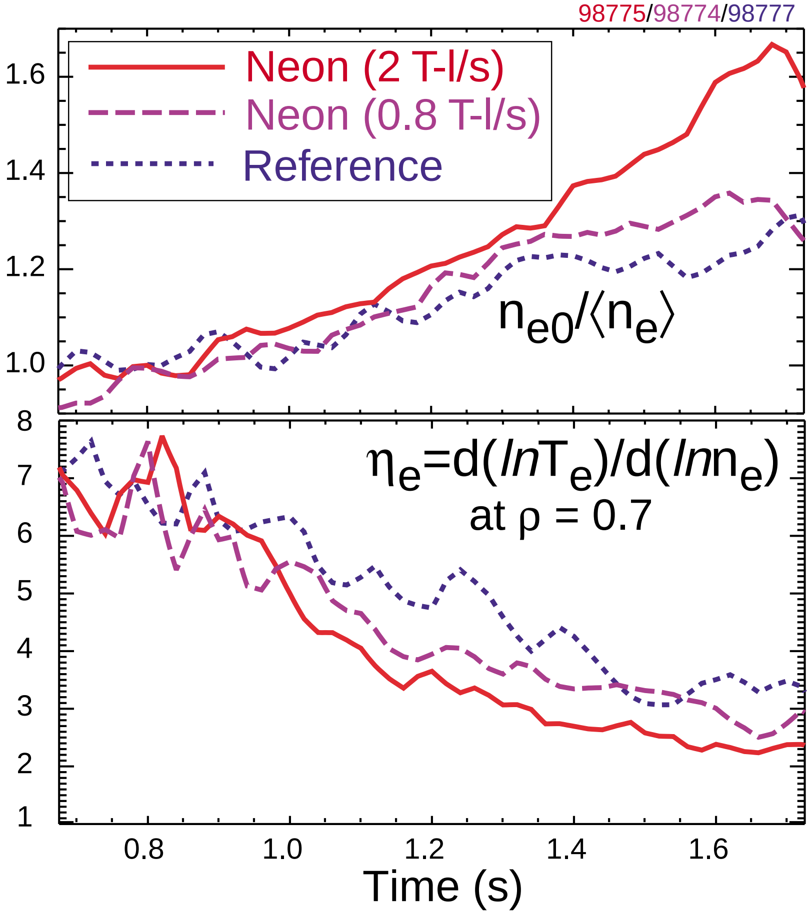
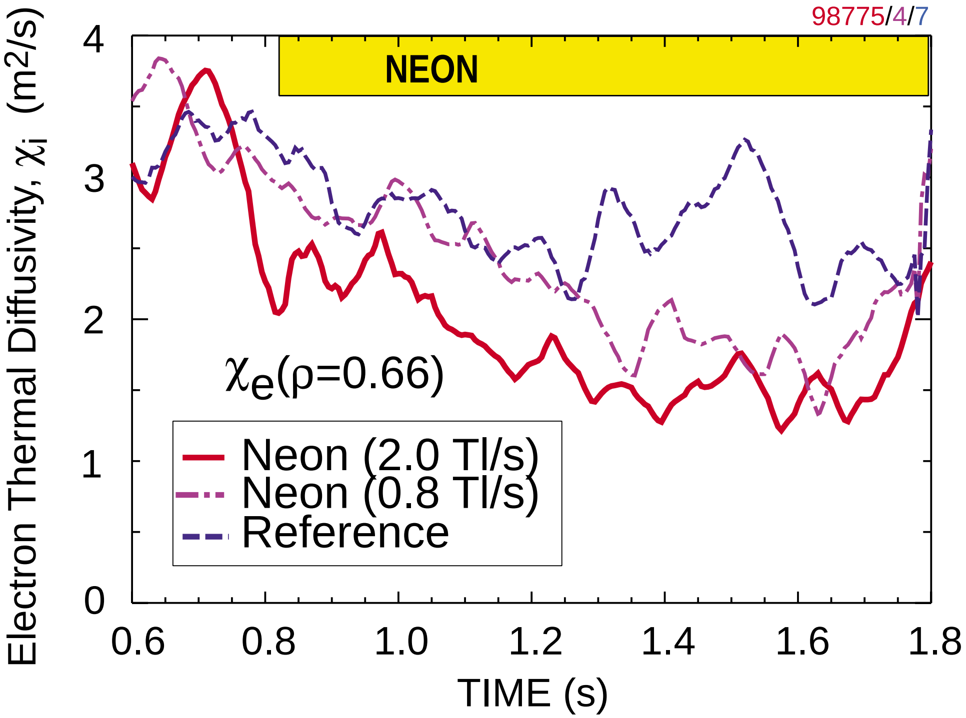
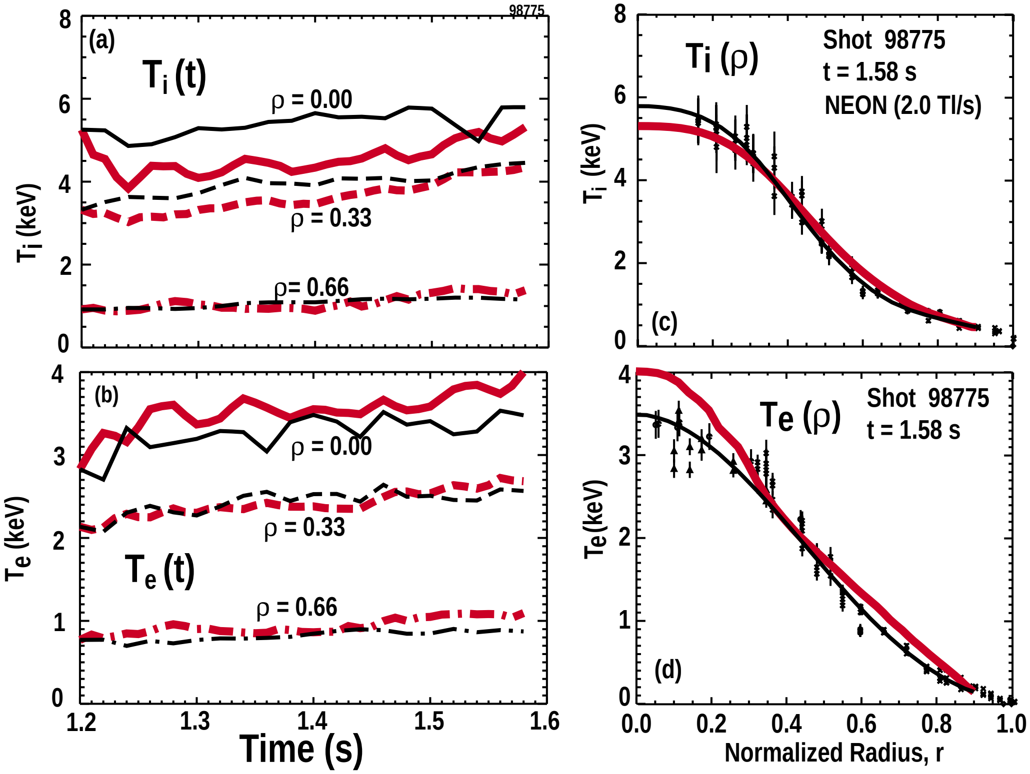
PLASMA PROFILES ALSO EVOLVE, HELPING TURBULENCE STABILIZATION





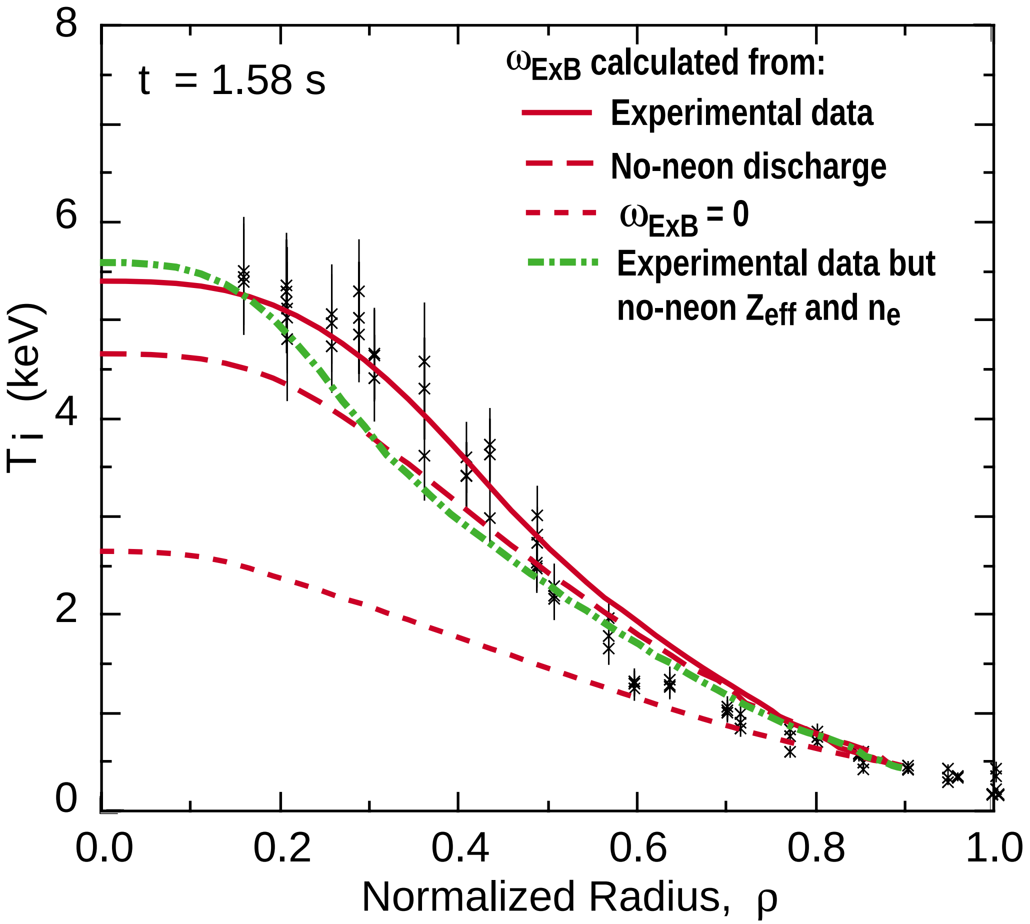
- **Can we separate these three effects?**
  - **Direct impurity effects for γ_{max}**
  - **ExB shear suppression**
  - **Other profile evolutions**

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 Demo 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 solved 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

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

⇒ Neon injection may be used as a trigger

ADDITIONAL EXPERIMENTS WITH SEVERAL DIFFERENT CONFIGURATIONS EXTENDED OUR UNDERSTANDING OF THE MECHANISMS

- **High-k fluctuation/electron transport correlation**
  - — FIR high-k fluctuation measurement:
    - Bursting fluctuations with neon injection and correlation of the average fluctuation levels with χ_e
    - Uncertainty of the fluctuation source exists because of the lack of a large E×B Doppler shift in the fluctuation spectrum
- **Divertor pumping effects**
  - — Initial experiments with a divertor pumping geometry at higher B_T (2.0 T) $\Rightarrow$ Smaller improvement than that at lower B_T (1.6T)
    - Lower neon content found in the core
    - Larger neon puff and reduced neon pumping geometry have produced τ_E as good as that at 1.6 T
- **Impurity species (Ne, Ar, Kr) scan**
  - — Ar and Kr injection can improve the confinement, but Ne is still the best
  - — Radiative loss fraction limit precludes mass density increase for stabilization with higher Z under DIII-D conditions
- **Neon injection into a circular, inner-limited discharge**

- **q-scan / B_T scan at constant ($\approx$ maximum) neon injection**

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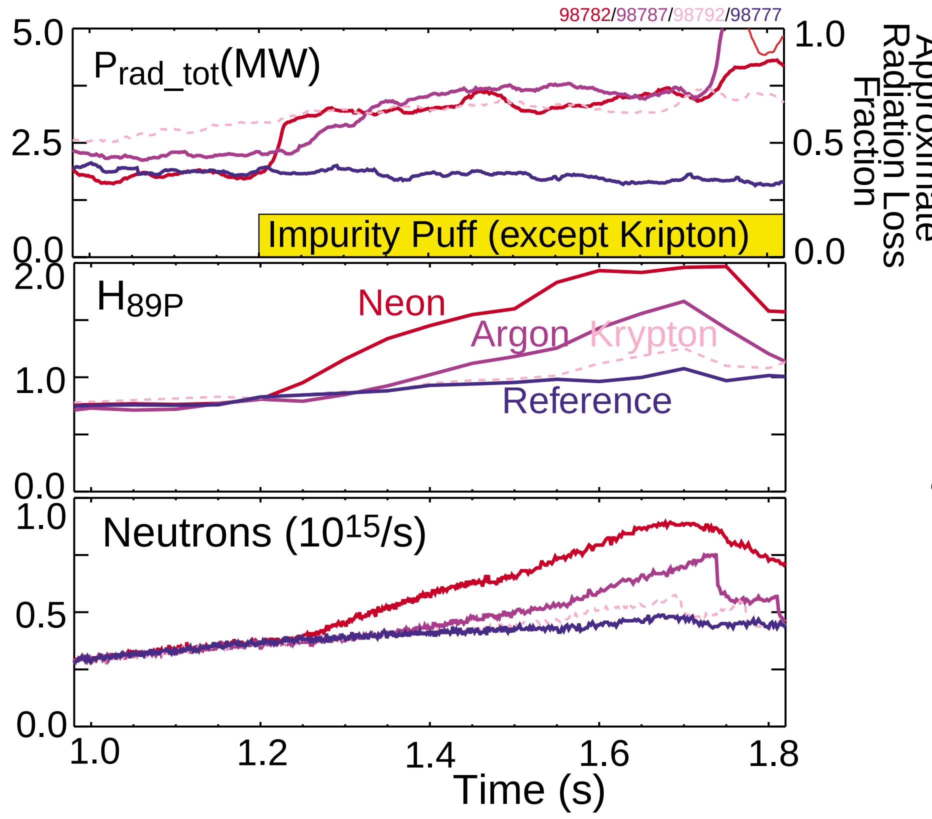
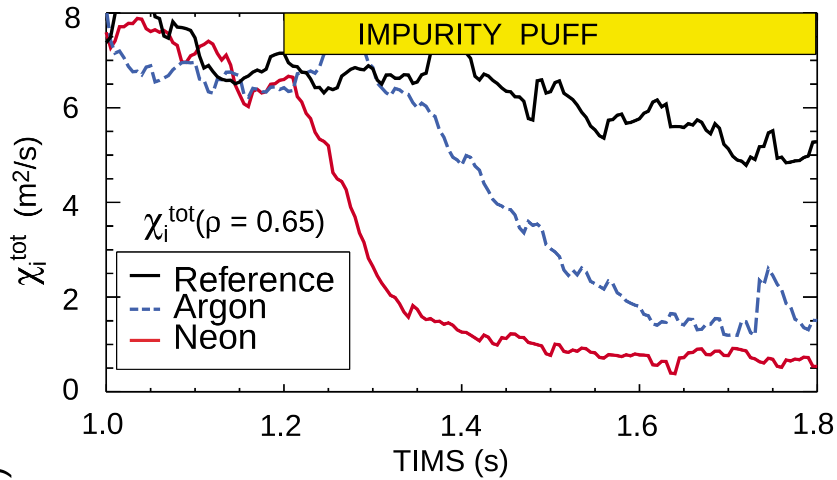
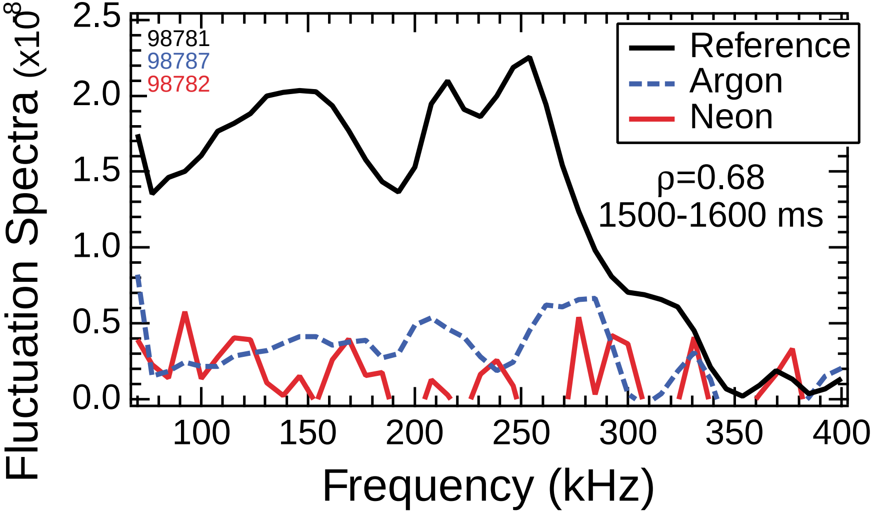
ARGON AND KRYPTON INJECTION CAN ALSO IMPROVE CONFINEMENT, BUT PLASMA RESPONCE IS SLOWER THAN NEON







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

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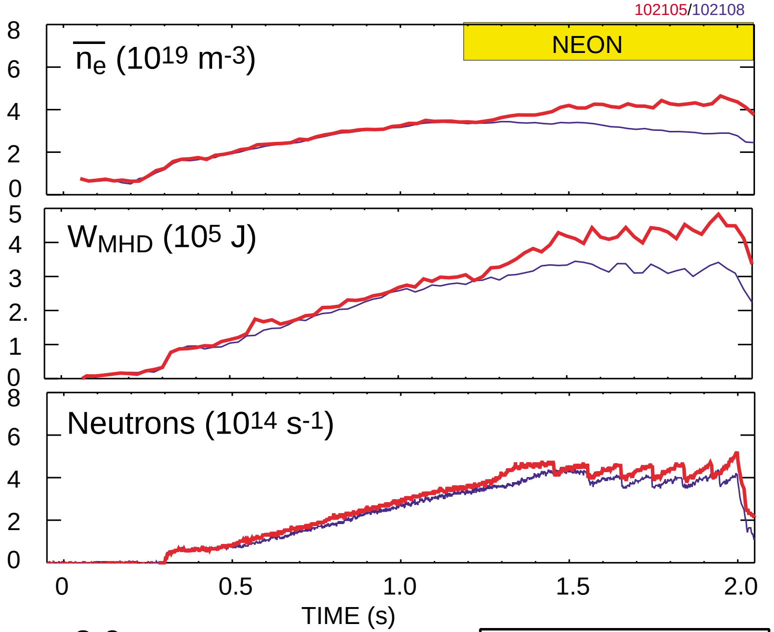
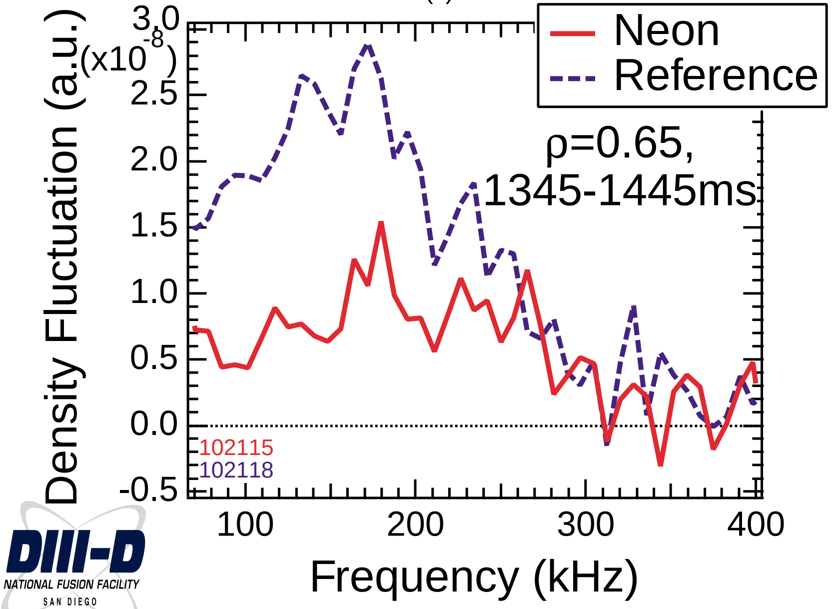
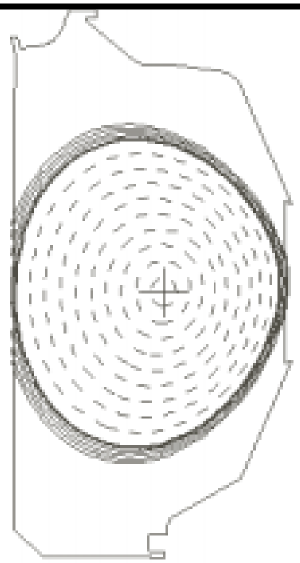
NEON INJECTION INTO A CIRCULAR, INNER-WALL LIMITED DISCHARGE EXHIBITS SAME FEATURE AS THAT IN A DIVERTED DISCHARGE, IMPLYING THE SAME PHYSICAL MECHANISM IS AT WORK







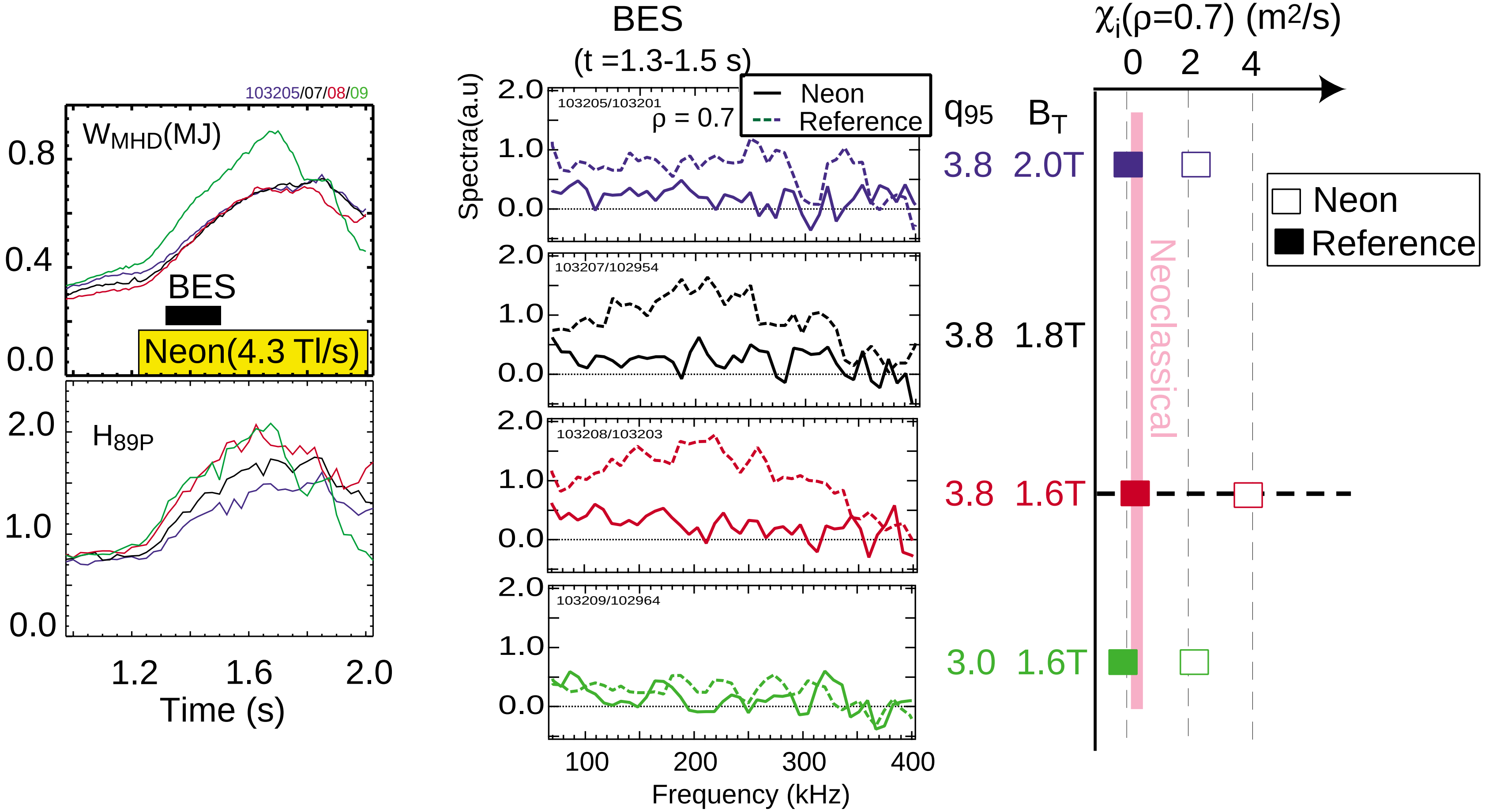
- **Improvement persists during sawtooth phase**
- **The turbulence suppression mechanism (reduced γ_{max} and increased ω_{ExB}) appears to be at work:**

	Neon	Reference
γ_{max}	0.19	0.43
ω_{ExB}	0.57	0.51

- **Density peaking factor with neon is even lower than no neon**

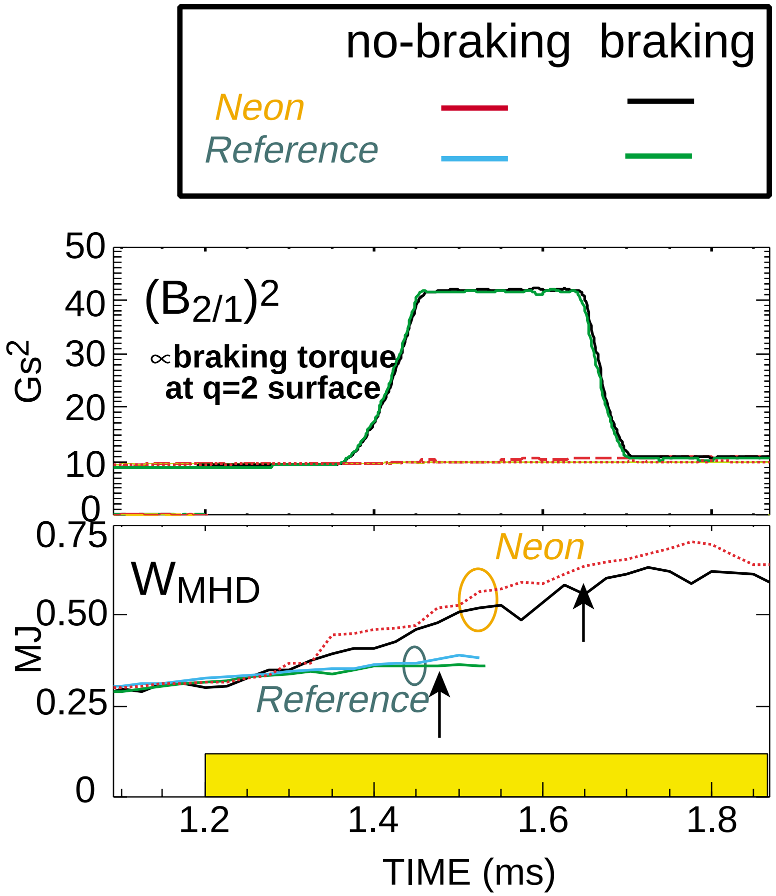
⇒ Density peaking is not a necessary condition for confinement improvement

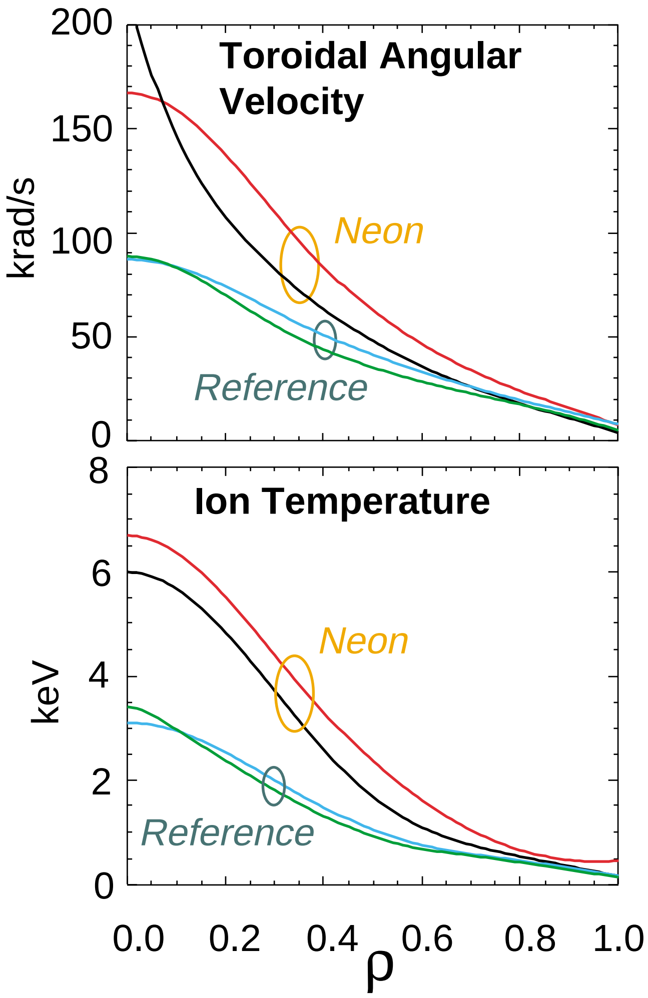
STRONG NEON INJECTION REDUCES BOTH LONG-WAVELENGTH TURBULENCE AND ION TRANSPORT TO THE MINIMUM LEVELS



- B_T and q_{95} scans with injection of a fixed (~maximum) quantity of neon
- χ_i with strong neon injection reaches neoclassical levels almost regardless the initial conditions
- Reduction of the fluctuation reaches near diagnostic detection level
- The overall performance with neon is determined by other parameters

MAGNETIC BRAKING EXPERIMENT SHOWED AN IMPORTANT ROLE OF ExB SHEARING IN IMPROVED CONFINEMENT WITH NEON INJECTION





[D.R. Ernst: MO1.9]

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
- Impurity species scan shows the neon producing the largest effect
- Neon injection into a circular, inner-limited discharge show similar characteristics, indicating common physics mechanisms with the above
- B_T and q scan with neon injection, showing ion transport approaching the neoclassical level
- Theory-based transport simulations (GLF23) and a magnetic braking experiment show the important role of E×B shearing suppression