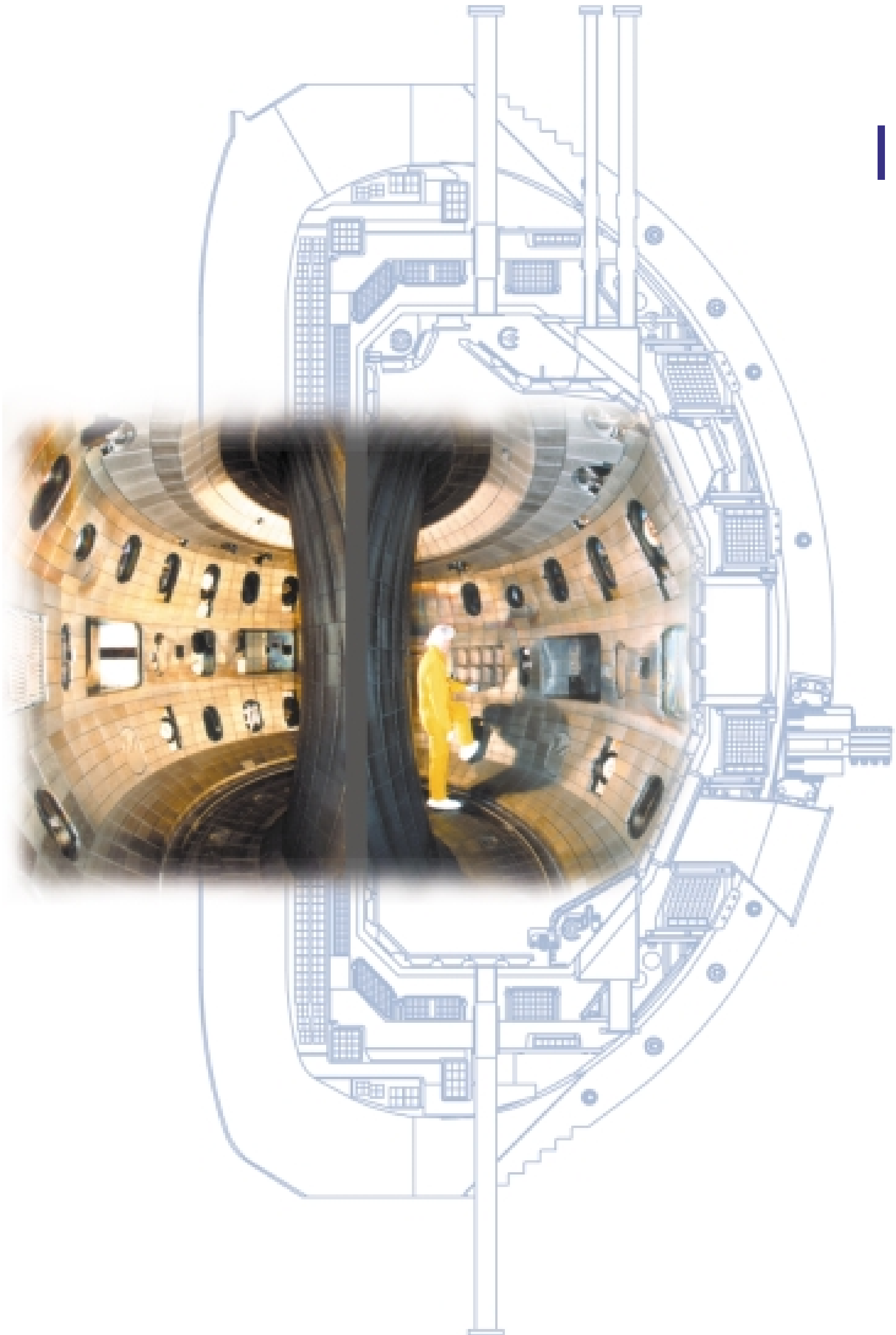

Impurity Seeding In L–, H–, and VH–Mode DIII–D Discharges

by

G.L. Jackson

with M. Murakami,* M.R. Wade,*

G.R. McKee,† B.W. Rice,‡

and the DIII–D Team

*Oak Ridge National Laboratory

†University of Wisconsin–Madison

‡Lawrence Livermore National Laboratory

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DIII–D

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Abstract Submitted
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Sorting Category: (Experimental)

Impurity Seeding in L-, H-, and VH-mode DIII-D Discharges[1] G.L. JACKSON, General Atomics, M. MURAKAMI, M.R. WADE, Oak Ridge National Laboratory, G.R. MCKEE, University of Wisconsin-Madison, B.W. RICE, Lawrence Livermore National Laboratory, AND THE DIII-D TEAM — During the 1999 DIII–D campaign impurity seeding, using Ne, Ar, and Kr, has been used to produce a radiating mantle and/or reduce edge pressure gradients in a variety of discharge configurations in DIII–D with either an H–mode or an L–mode edge. In L–mode discharges, clear increases in confinement have been observed ($H \leqq 2$) which are directly correlated with impurity injection. Interestingly, the impurity seeded phase also exhibits an increase in the neutron rate by a factor of 2. Nearly circular limited discharges have also been obtained with characteristics similar to the TEXTOR RI–mode (τ_{E} increases with n_{e} in L–mode with NBI co-injection). In addition to the observations described above, we will present an overall summary of the 1999 impurity injection experiments including the first observations of confinement improvement with neon puffing and counter neutral beam injection. The reduction of edge pressure gradients with krypton injection into VH-mode discharges will also be presented.

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X Prefer Oral Session
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G.L. Jackson
jackson@gav.gat.com
General Atomics

Special instructions: DIII-D Contributed Oral Session, immediately following KL Wong

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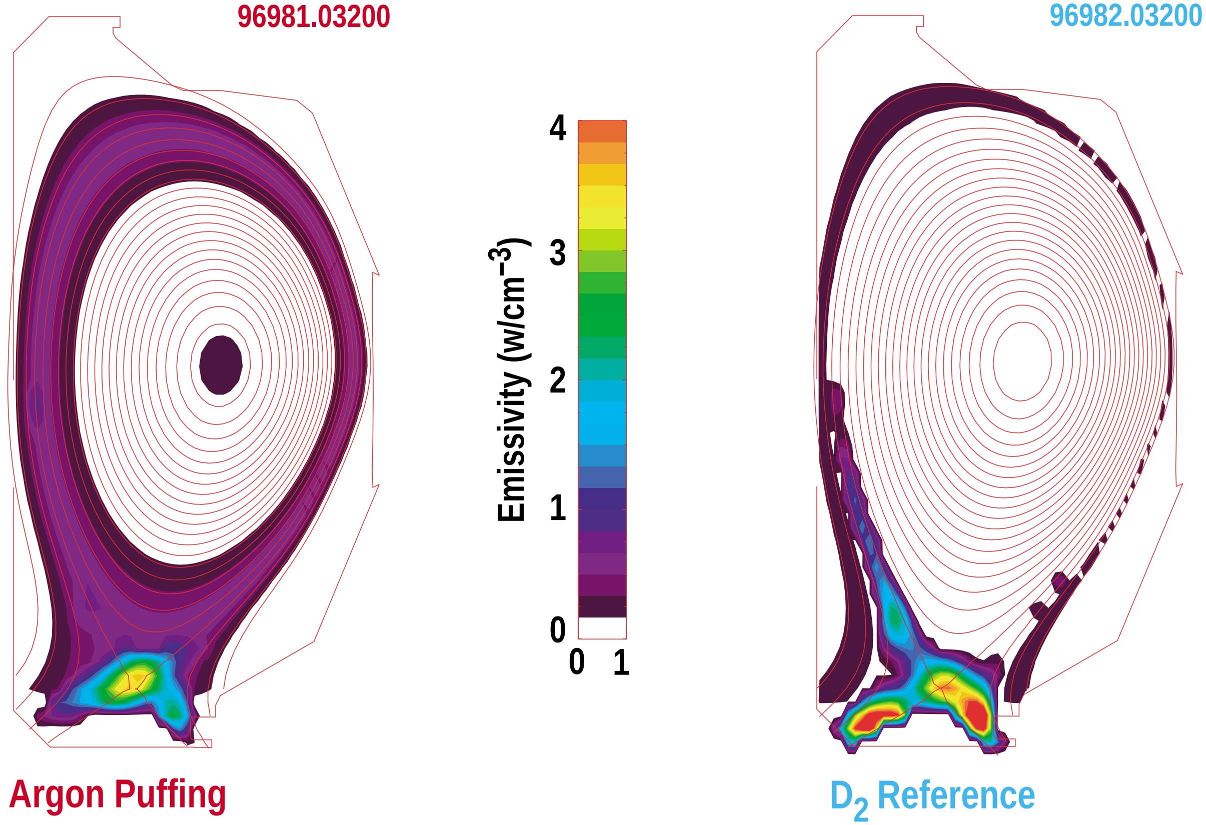
IMPURITY SEEDED DISCHARGES CAN ACHIEVE GOOD PERFORMANCE, H ≥ 2, AND LOWER PEAK HEAT FLUXES TO PLASMA FACING SURFACES

7.4	P_{tot} (MW)	5.3
2.3	P_{div} (MW)	3.0
3.7	P_{core} (MW)	0.8



DIII–D HAS EXTENDED PREVIOUS RI–MODE IMPURITY EXPERIMENTS IN CIRCULAR, LIMITED TOKAMAKS (ISX-B, TEXTOR) TO A VARIETY OF CONFIGURATIONS

- **L–mode**
  - Upper single-null divertor (McKee BI2.06; Murakami, GO2.06; Sydora, UPI.51), $\beta_N H \leq 6$
  - Inner wall limited
    - ★ Co-injection (TEXTOR-like RI–mode)
    - ★ Counter-injection (First observations in any device with enhanced confinement and impurity seeding)

- **H– and VH–mode**
  - Lower single-null divertor puff and pump ELMing H–mode at densities near the Greenwald limit
  - Double-null divertor VH–mode with reduced edge pedestal pressure and longer ELM-free periods (Ferron, UI1.01)

REDUCTIONS IN TURBULENCE GROWTH RATES ARE BOTH OBSERVED AND PREDICTED WITH IMPURITY INJECTION (McKee, BI2.06)

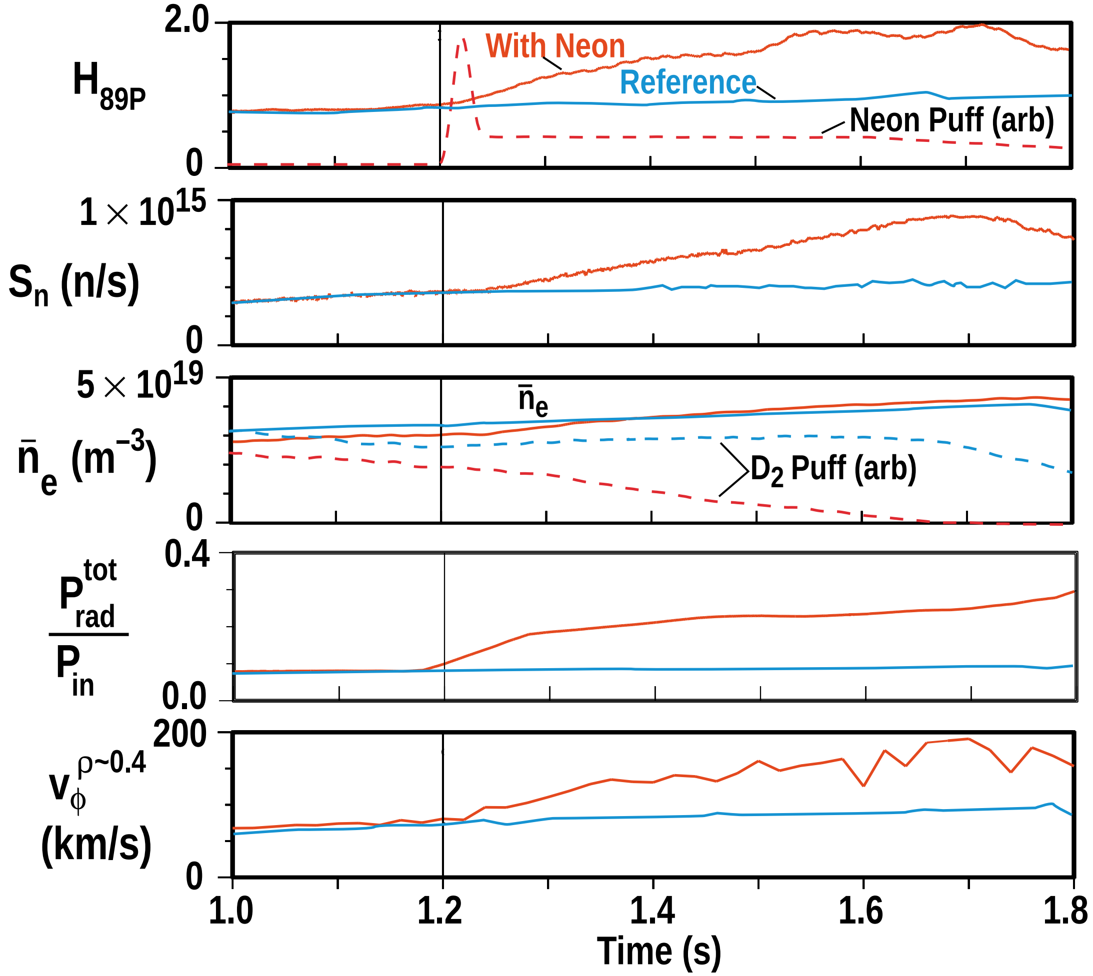
- **Observations**
  (extensively evaluated for upper single-null divertor)
  - $\tilde{n}$ promptly decreases with impurity injection

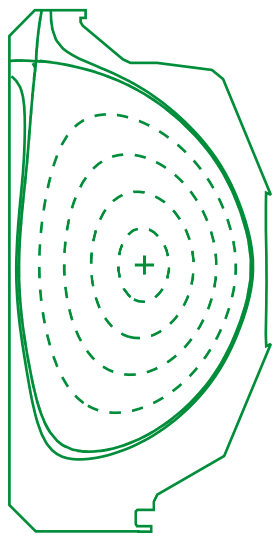
  (common in all configurations with impurity seeding)
  - Higher W_{MHD} and global energy confinement time
  - Electron density monotonically increases
  - Core toroidal rotation and rotational shear increase
  - χ_i is reduced

- **Model for impurity behavior**
  - Growth rate of turbulence is a function of mass and decreases with increasing impurity concentrations
  - Introduction of impurities acts as a trigger to reduce turbulence
  - Reduction in turbulence leads to improved transport and larger E×B shear
  - Increased E×B rotational shear further stabilizes microturbulence creating a positive feedback loop

- **GKS simulations of DIII–D impurity seeded discharges show reduced turbulence growth rates consistent with this model**

NEON SEEDED DISCHARGES SHOW ENHANCED CONFINEMENT AND HIGHER NEUTRON RATES





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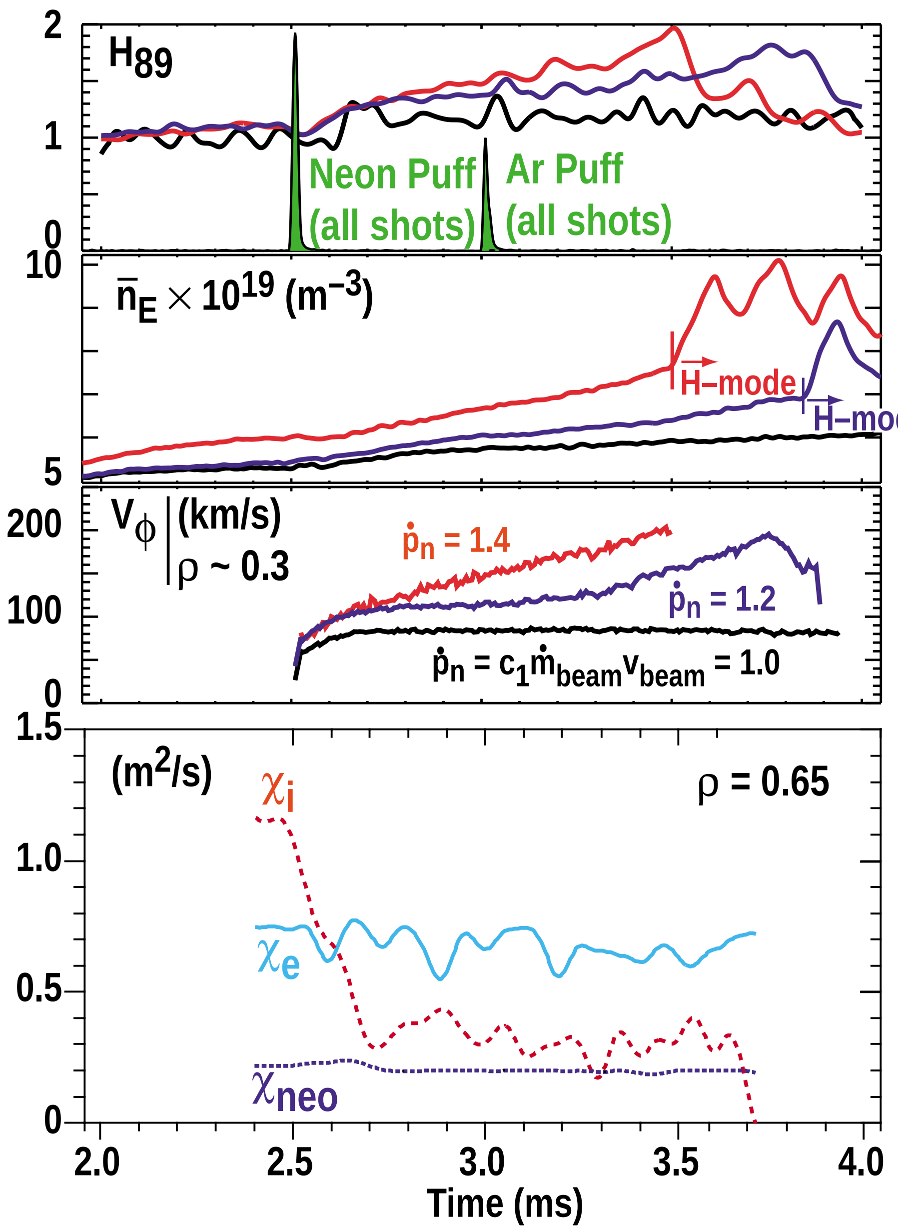
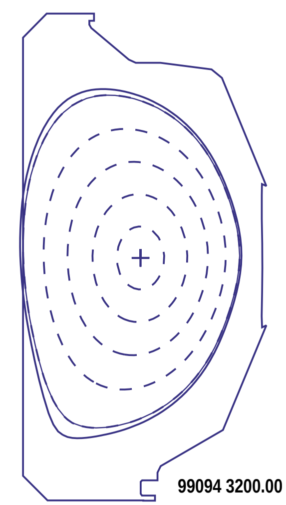
IMPROVED CONFINEMENT HAS BEEN OBTAINED WITH COUNTER INJECTION AND IMPURITY SEEDING



- Highest confinement occurs with highest momentum input
- No RI-mode observed in TEXTOR with pure counter injection



(4.4 MW, 1.6 MA, 2.1 T)

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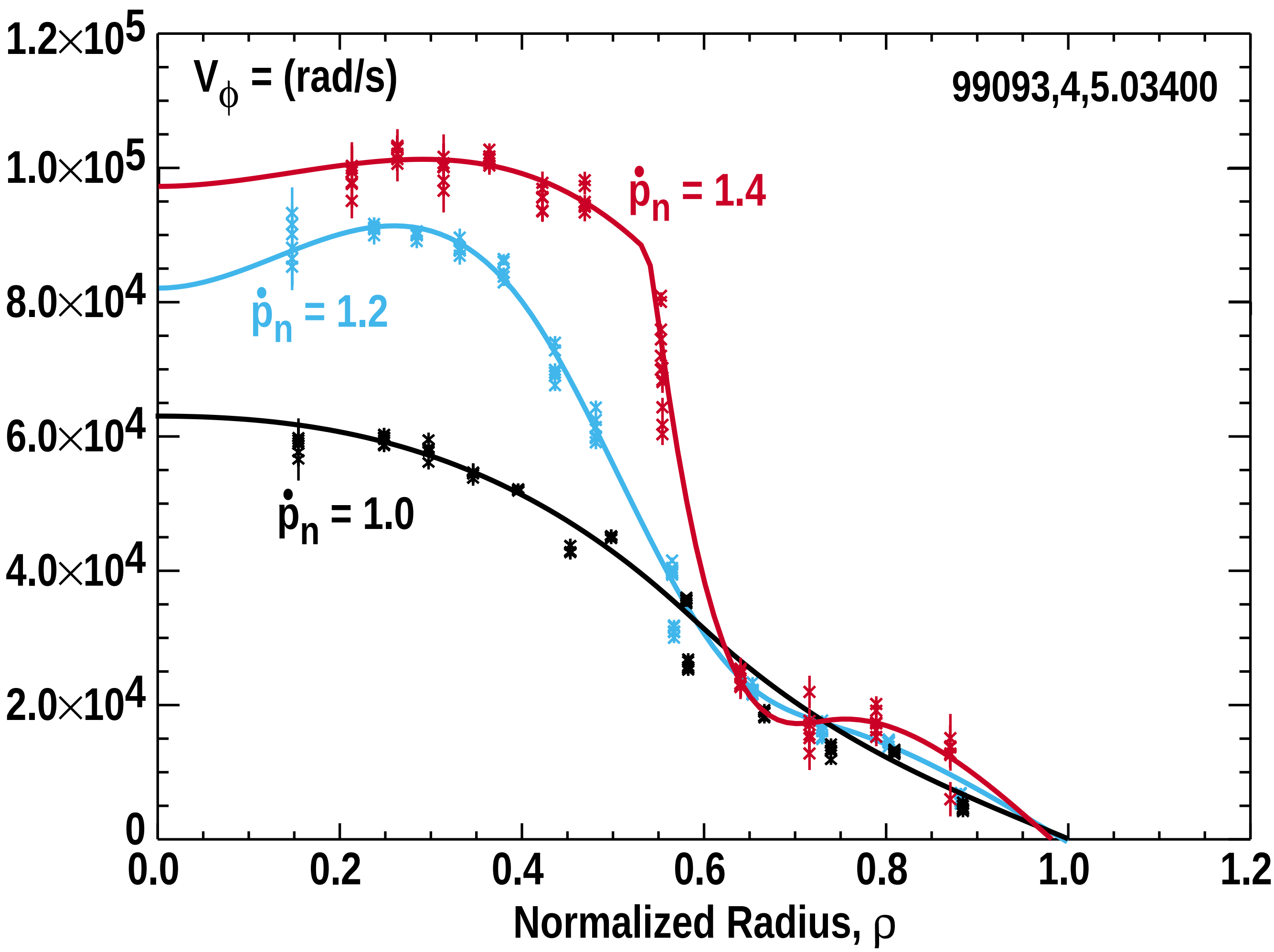
TOROIDAL ROTATION AND ROTATIONAL SHEAR INCREASE AS BEAM MOMENTUM INCREASES (P_{nb} = 4.4 MW, COUNTER INJECTION)



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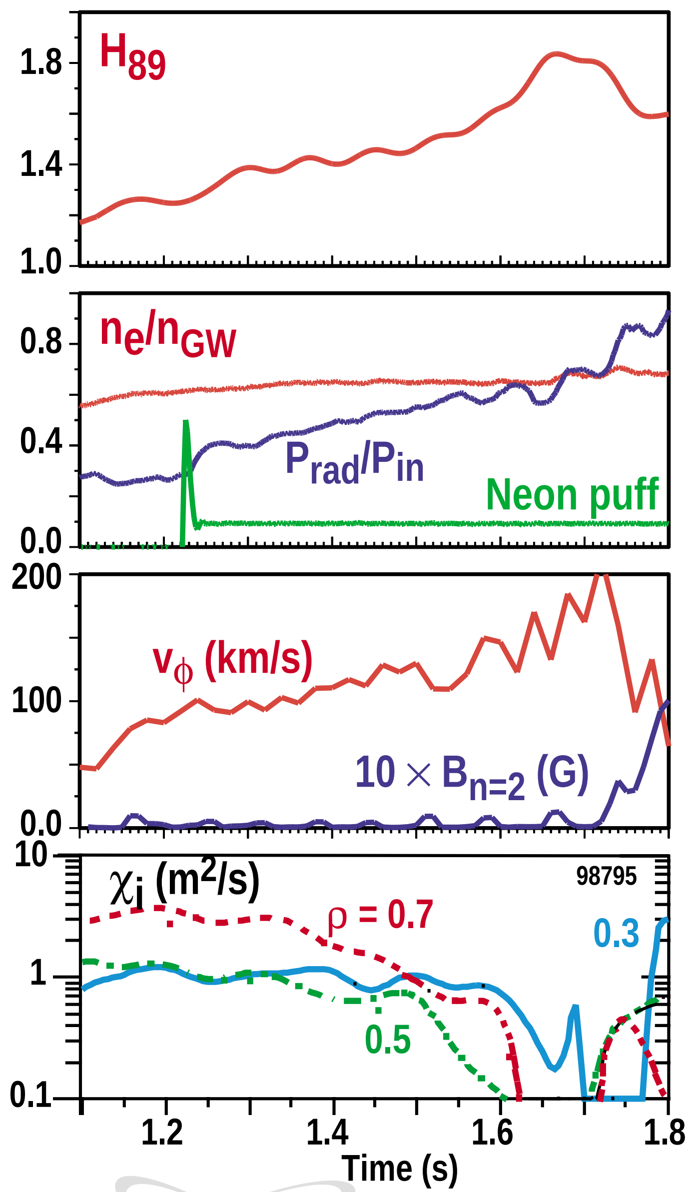
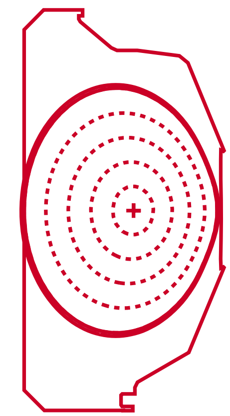
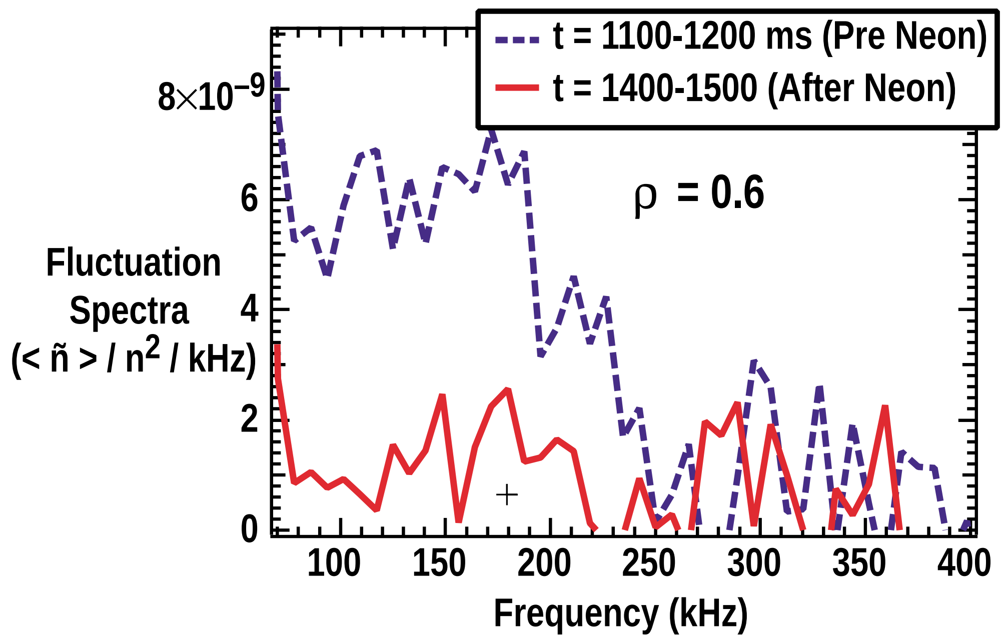
TEXTOR-LIKE RI–MODE HAS BEEN OBSERVED IN DIII–D





- Shape and q are similar to TEXTOR
- n_e/n_{GW} and P_{rad}/P_{in} are within the range for RI-mode in TEXTOR
- χ_i is reduced, v_ϕ increases, and ñ drops with neon puffing
- RI–mode phase is terminated by n = 2 MHD



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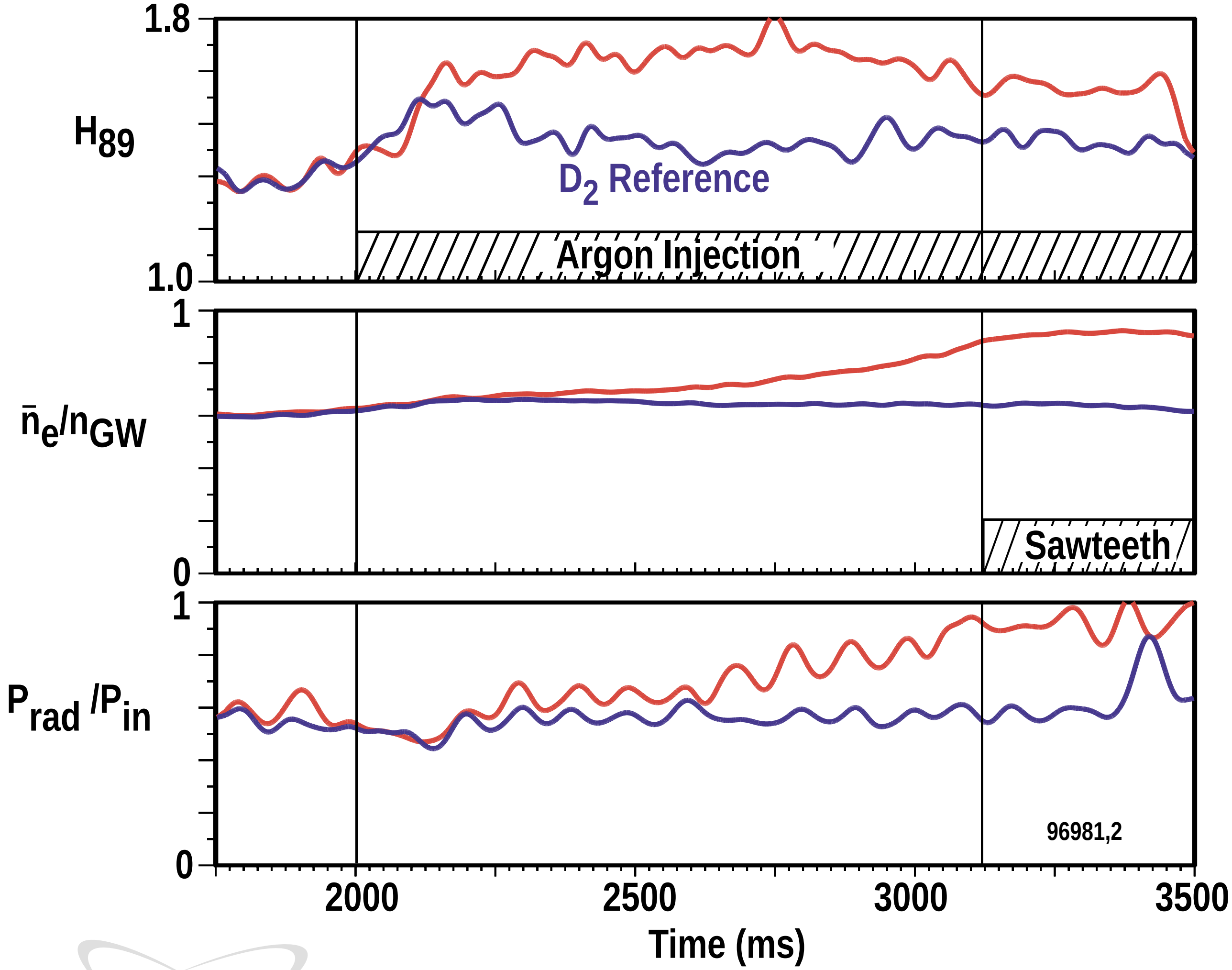
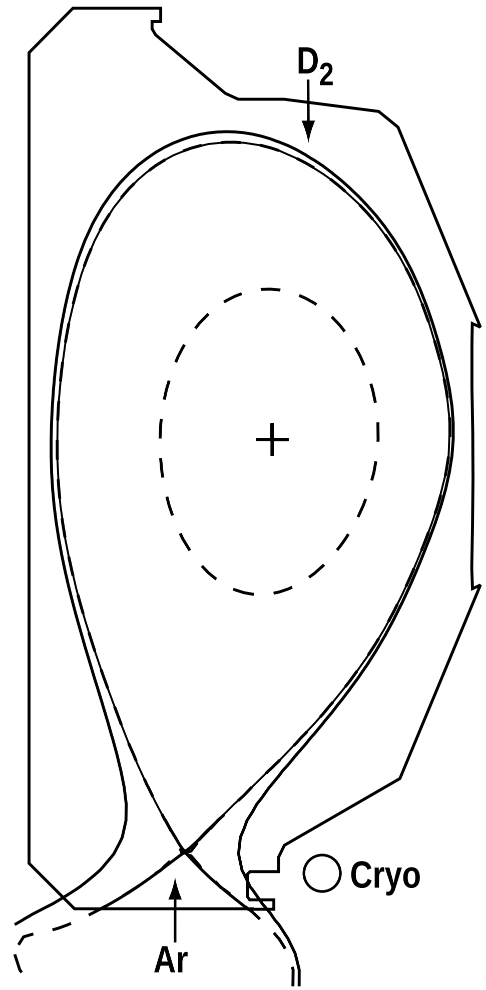
CONFINEMENT SCALING OF DIII–D L–MODE IMPURITY SEEDED DISCHARGES

- No clear density scaling of τ_E as observed in TEXTOR
  - For a given configuration and operational scenario, τ_E can increase with density but at lower normalized density than observed in TEXTOR
- DIII–D L–mode impurity seed discharges show confinement enhancements up to, and above, ELM-free H–mode confinement
- Confinement increases up to a factor of two when compared to similar discharges without impurity injection

ELMing H–MODE DISCHARGES WITH HIGHER CONFINEMENT AT HIGHER DENSITY ARE OBTAINED WITH IMPURITY INJECTION





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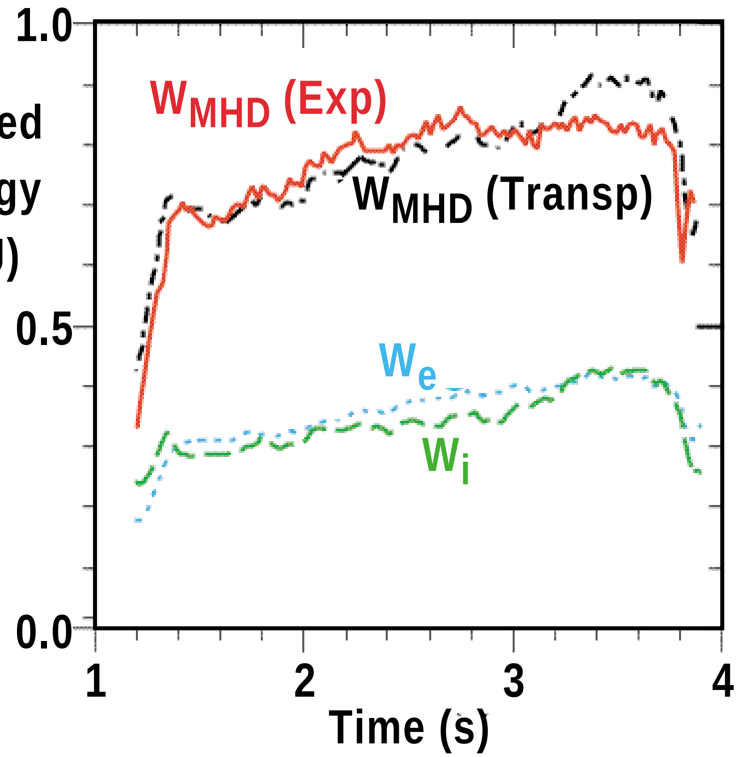
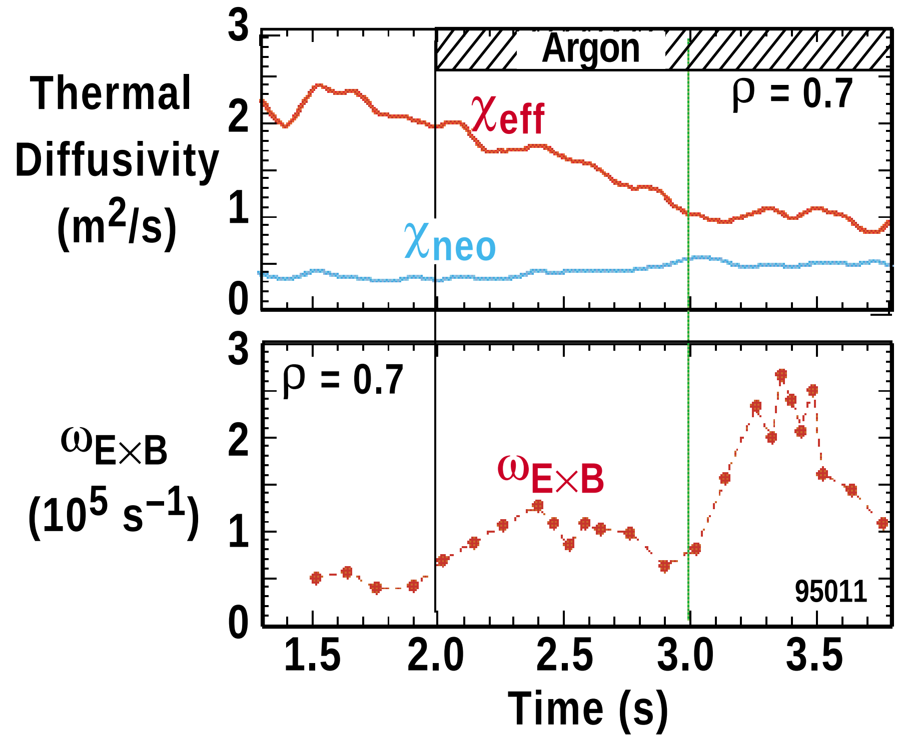
χ_{eff} DECREASES AND E×B SHEARING RATE INCREASES AFTER ARGON INJECTION IN ELMING H–MODE DISCHARGES





- Both ion and electron confinement improve after argon injection
- Improvement after a spontaneous transition (3.0 s) is primarily in the ion channel

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SUMMARY

- Impurity induced improved confinement scenarios have been observed in DIII–D in a variety of configurations
  - L–mode and ELMing H–mode
  - Diverted and limited shapes
  - Co- and counter-injection
- Similar behavior in all configurations leads us to propose a common physical mechanism to describe the impurity behavior
  - Impurities are a trigger to reduce the growth rate of turbulence
  - Transport improves and the $E \times B$ rotational shearing rate increases
  - $E \times B$ shear stabilization further reduces the growth rate of turbulence producing a positive feedback loop
- Future work
  - Further examine the role of turbulence suppression as the underlying mechanism in all impurity seeded scenarios
  - Extend the duration of these discharges

DISCHARGE IMPURITY CONTENT VARIES WITH IMPURITY PUFFING SCENARIO

- Puff and pump ELMing H–mode exhibits a hollow impurity density profile with Z_{eff}(core) < 2

- Lowest density discharges, $n_e/n_{GW} < 0.4$, can have $Z_{eff} > 4$ after sawteeth begin

- Low density upper single-null discharges with neon puffing exhibit increased neutron reactivity when directly compared to deuterium fueled reference discharges