H-mode Discharges with High Energy Confinement above the Greenwald Limit on DIII-D

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H-Mode Discharges with High Energy Confinement Above the Greenwald Density on DIII-D[1] T.H. OSBORNE, M.A. MAHDAVI, A.W. LEONARD, T.W PETRIE, General Atomics, E.J. DOYLE, C.L. RETTIG, University of California, Los Angeles, M.E. FENSTERMACHER, Lawrence Livermore National Laboratory, G.R. MCKEE, University of Wisconsin, M.R. WADE, Oak Ridge National Laboratory — In experiments on DIII–D densities as high as $n/n_{\rm Greenwald} = 1.4$ with $H_{\rm ITER89P} = 1.9$ were obtained with gas puffing combined with pumping of the divertor private flux region. Obtaining good confinement at high density required the H–mode pedestal pressure, $p_{\rm PED}$, be maintained during gas puffing. This not only maintains the pedestal energy, but also allows the central pressure to be maintained even for a rigid temperature profile if the density profile is similarly peaked at low and high density. At low triangularity, δ, $p_{\rm PED}$ was maintained with gas puffing and H was recovered as the density profile gradually peaked. At high δ, H was initially higher as a result of a higher ELM critical pressure gradient at high δ, however $p'_{\rm EDGE}$, and hence $p_{\rm PED}$, were strongly reduced with gas puffing, and H did not recover even with significant density profile peaking.

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[X] Prefer Oral Session
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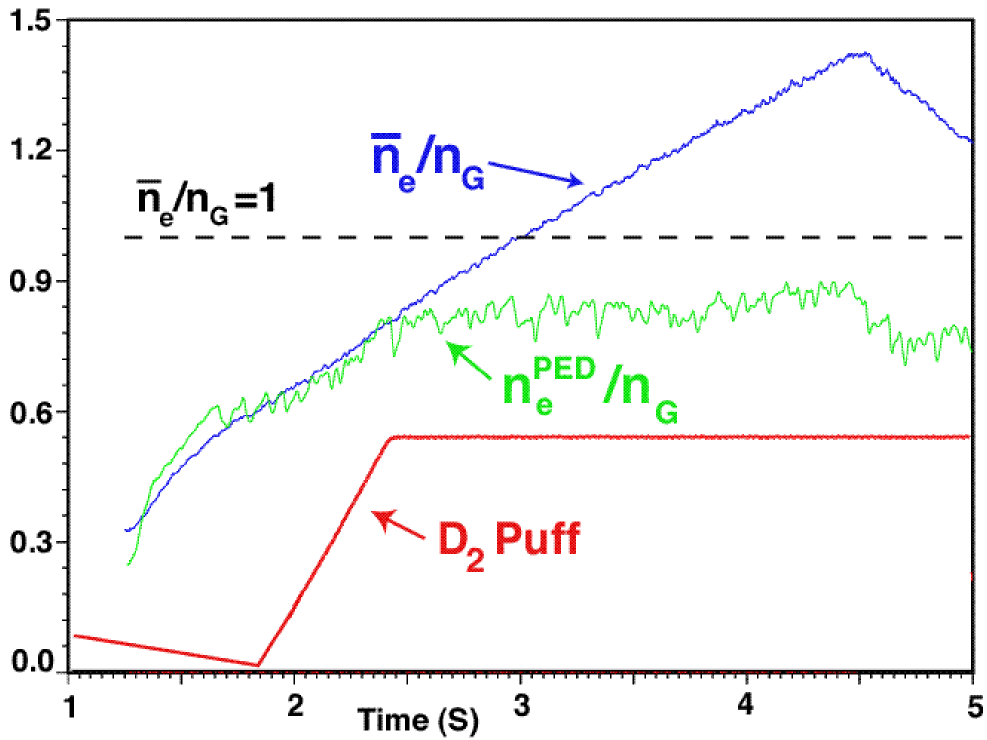
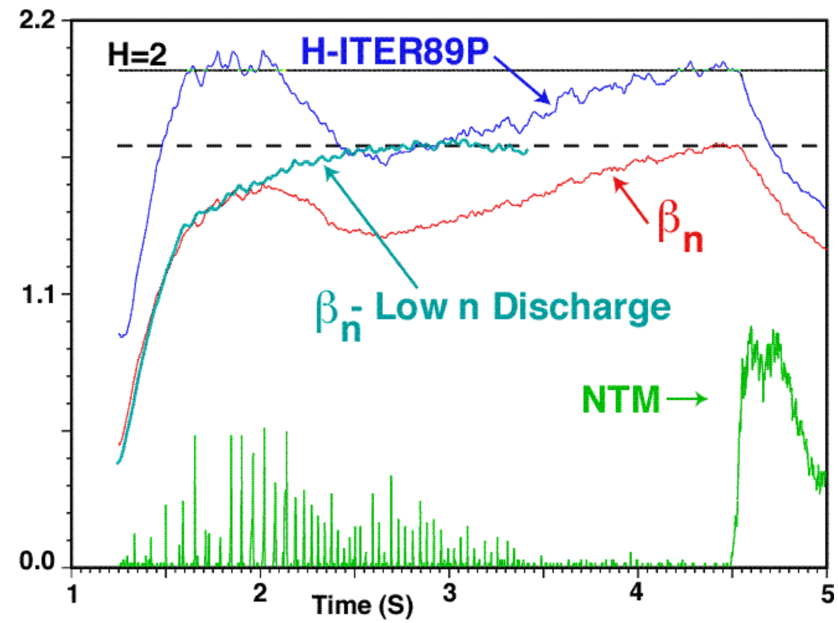
H-mode Discharges with High Energy Confinement above the Greenwald Limit on DIII-D

- High density, $n_e > n_{G,}$ achieved with gas puff fueling.
- Plasma stored energy, W, increases with density after an initial decrease: $H_{89P} = 2$ at $n/n_G = 1.4$.
- n and W increase limited by MHD





$$n_G(10^{20}\,m^{-3}) = \frac{I_P(MA)}{\pi a^2(m)} \approx 1.1$$

$$H_{ITER89P} = \tau_E/(I_p^{0.85} R^{1.2} a^{-0.11}\, \bar{n}_e^{0.17}\, B_T^{0.32} \kappa^{0.66} / P_L^{0.67})$$

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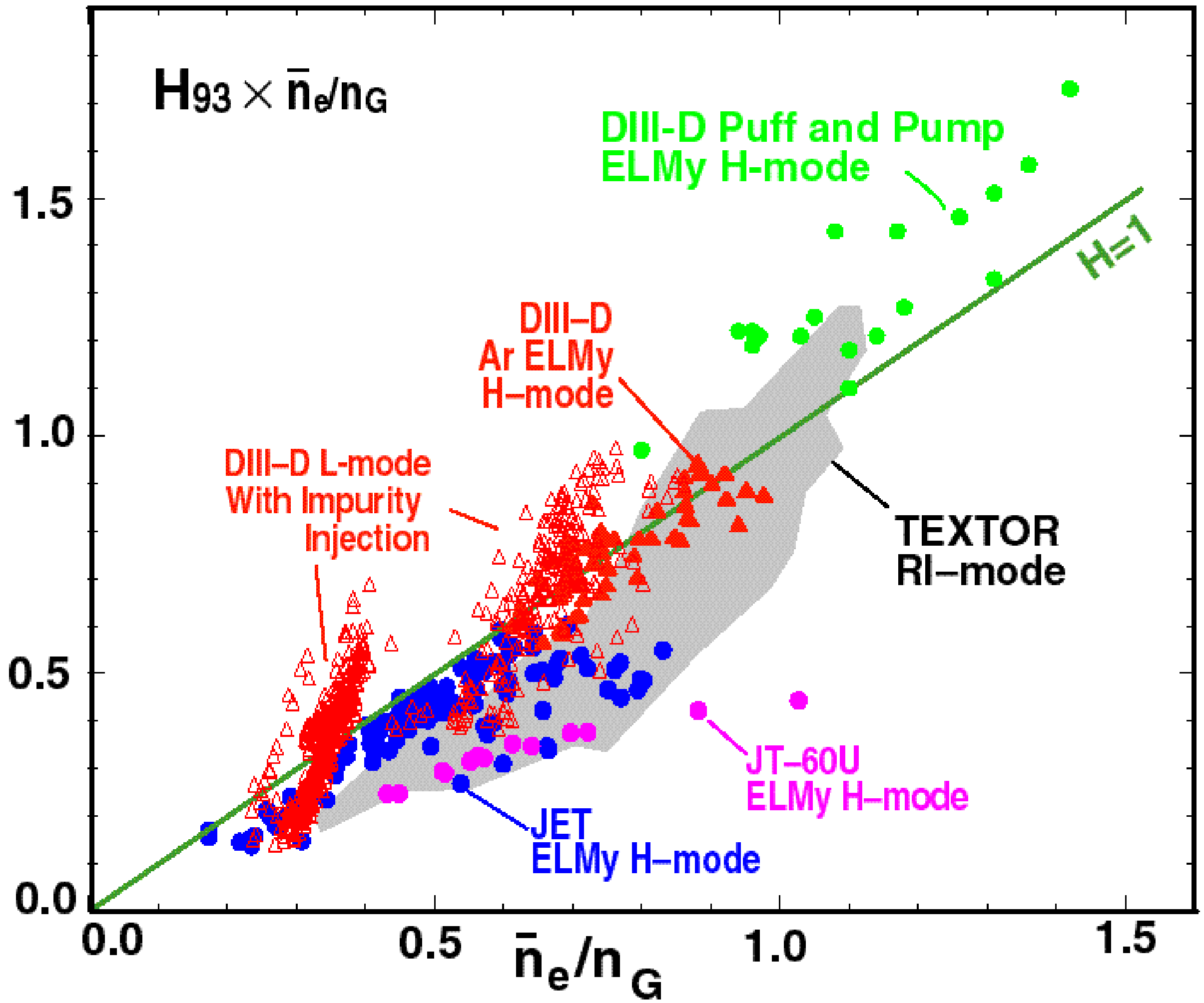
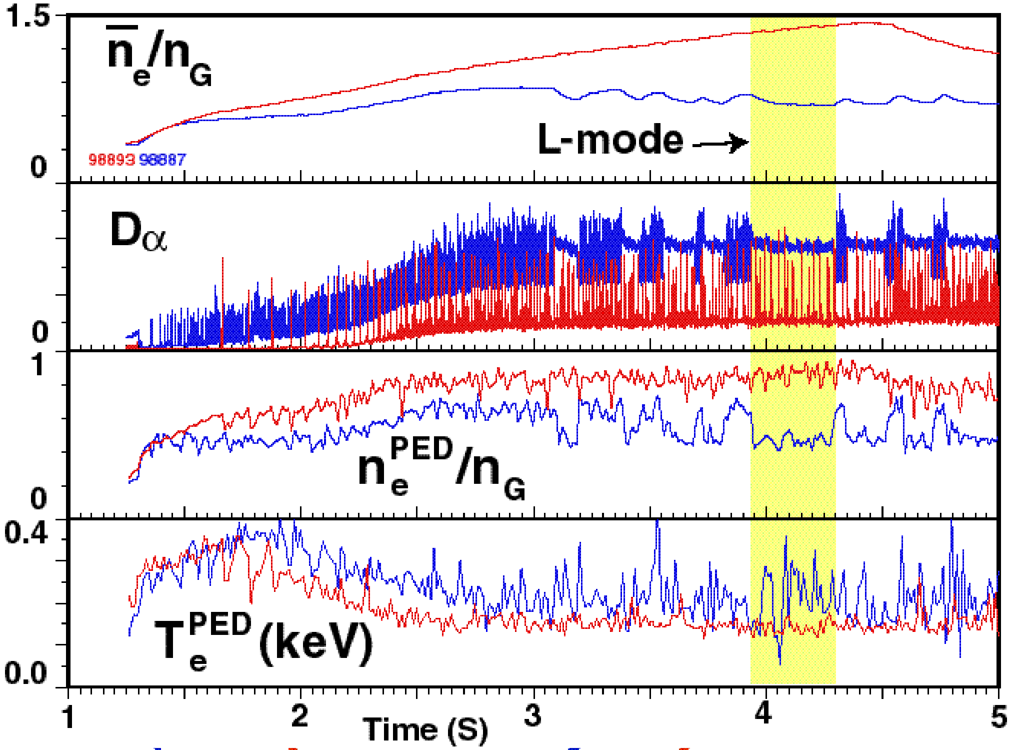
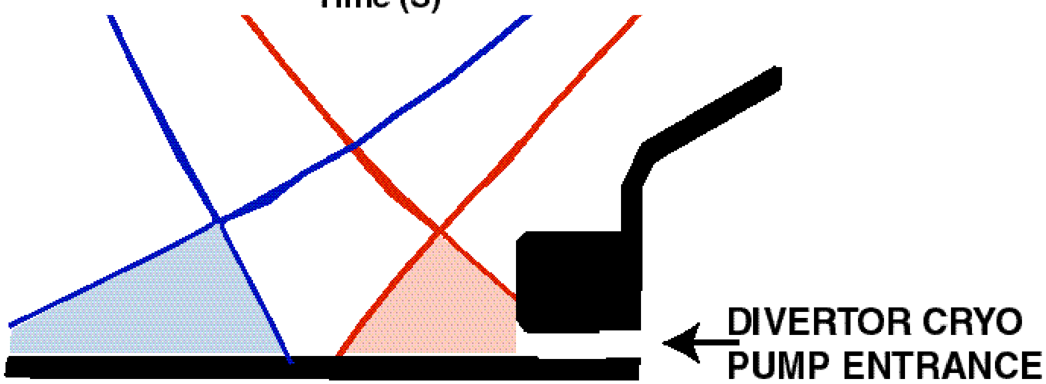
Energy Confinement at High Density is Improved over Previous Results on DIII-D

- Fusion reactors require high energy confinement at high density to achieve high Q.



High Density Gas Fueled Discharges with Good Energy Confinement were Obtained with Divertor Pumping

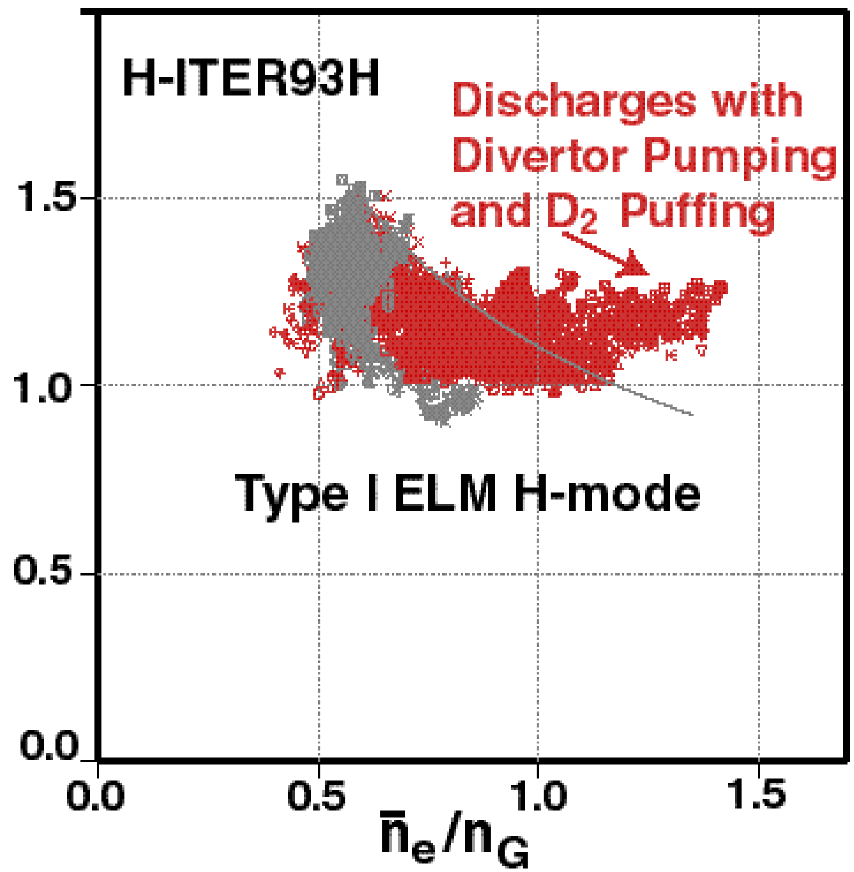




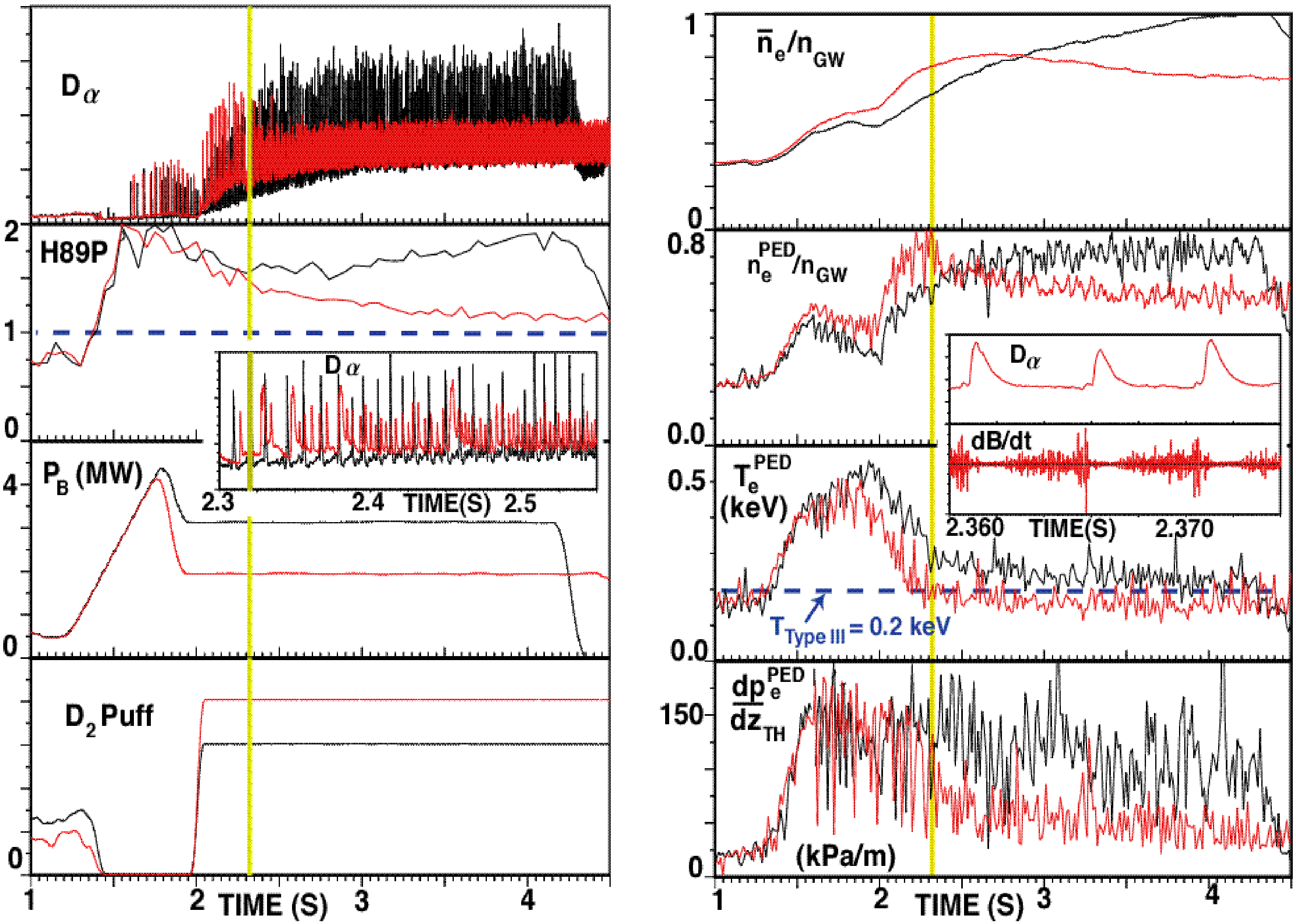
- All high density gas puff fueled discharges employed pumping of the divertor region.
  - Allows high pedestal density without Type III ELMs, H->L, or MARFE
- Best performance was obtained with pumping of the divertor private flux region.
  - Possibly by reducing neutral density in the private flux region near the x-point.

Causes of Energy Confinement Degradation at High Density With Gas Puff Fueling

- Core profiles degraded in response to changes in H-mode pedestal parameters
  - Temperature profile stiffness.
  - Density profile broadening.
- Loss of H-mode
  - T^{EDGE} or p^{EDGE} below a critical value.
- X-point MARFE Loss of H-mode
- Transition for Type I to Type III ELMs.
  - T^{EDGE} or p^{EDGE} below a critical value.

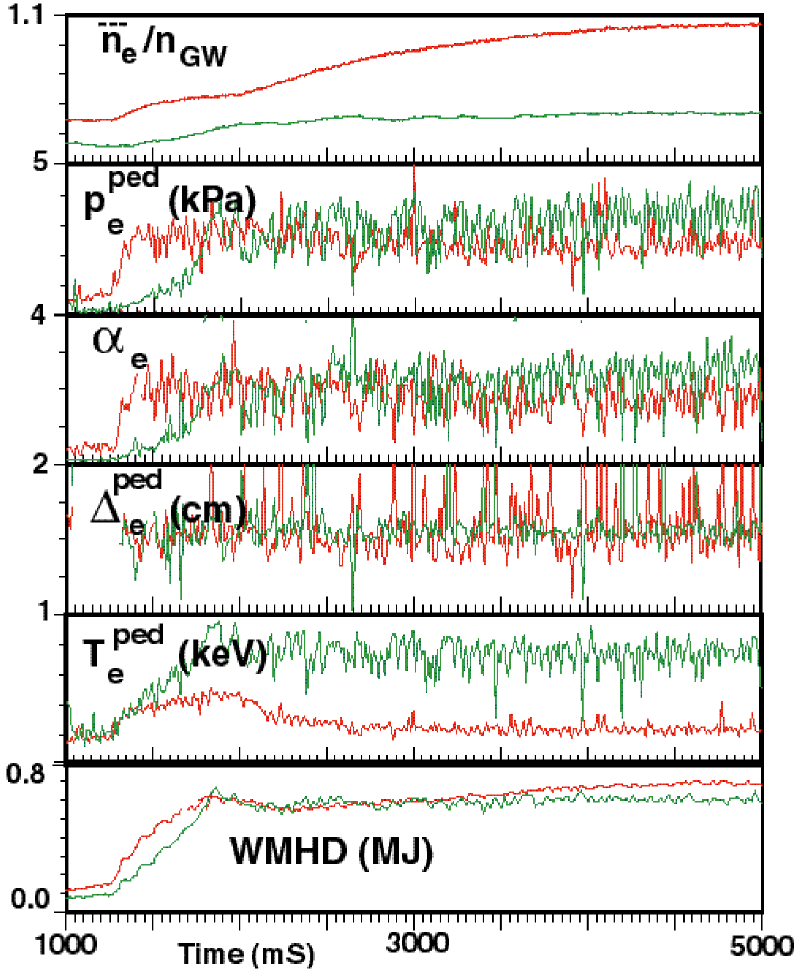


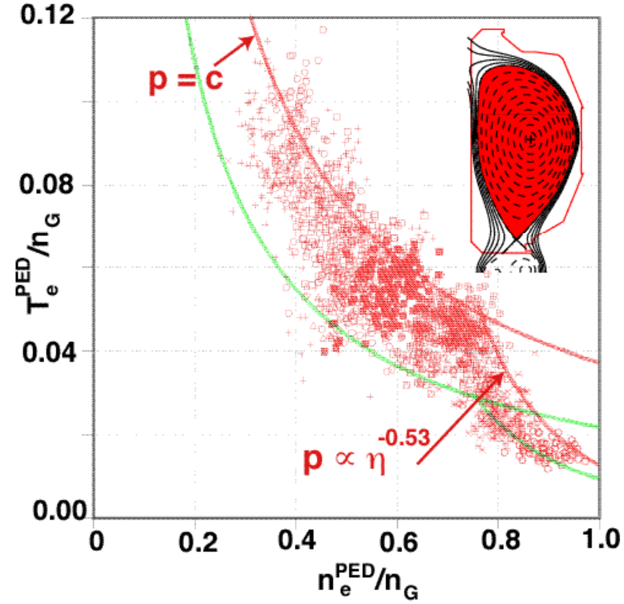
Excess D2 Puffing at Low heating Power Can Lead to Type III ELM Onset and Loss of Confinement.

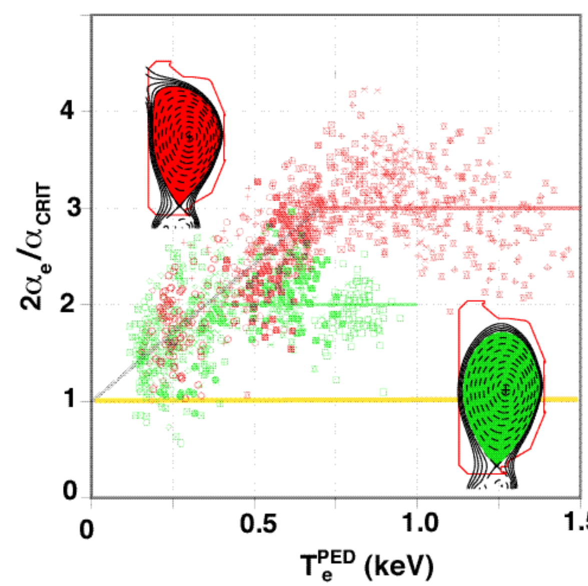


Response of H-mode Transport Barrier to Gas Puffing in Type I ELM Discharge

- p^{PED} can be reduced with D_2 puff.
  - p reduced
  - Width, Δ, relatively fixed.







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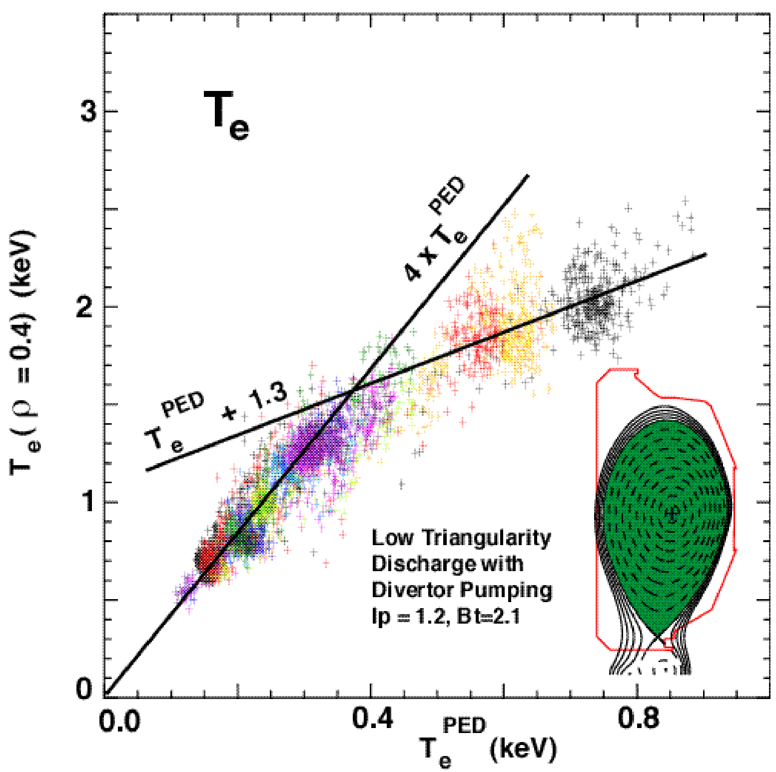
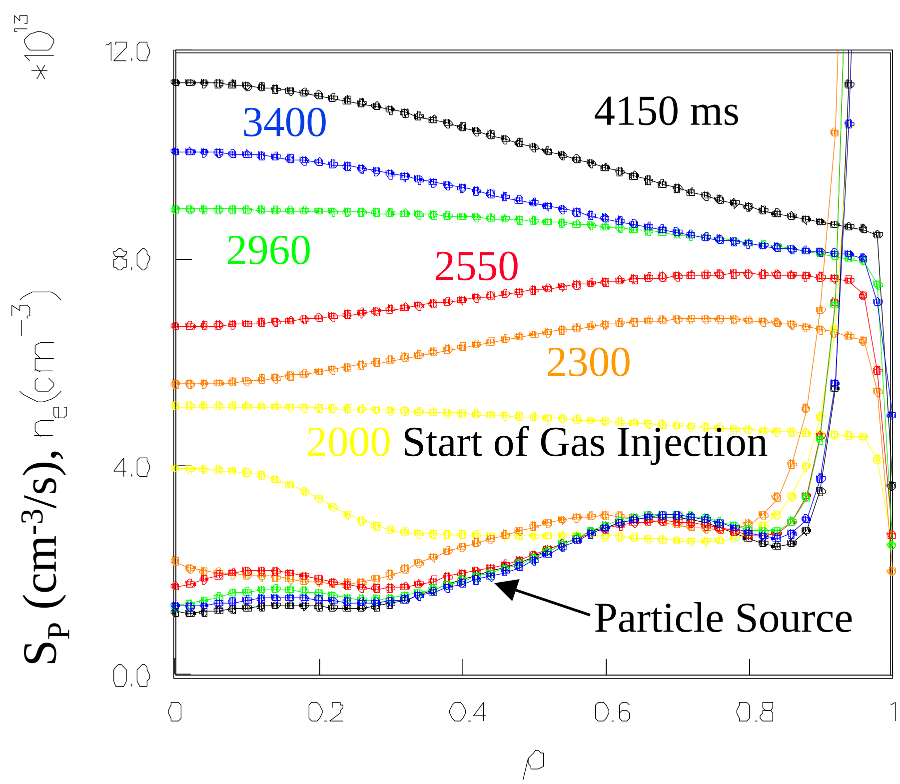
Response of Core Plasma to Change in Pedestal Involves Density as Well as Temperature Profile

- Stiff temperature profile

$$T(\rho) = T^{PED} \times f(\rho) \qquad W^{TOTAL} \propto p^{PED}\left(c_1 + c_2 \frac{\bar{n}}{n^{PED}}\right)$$

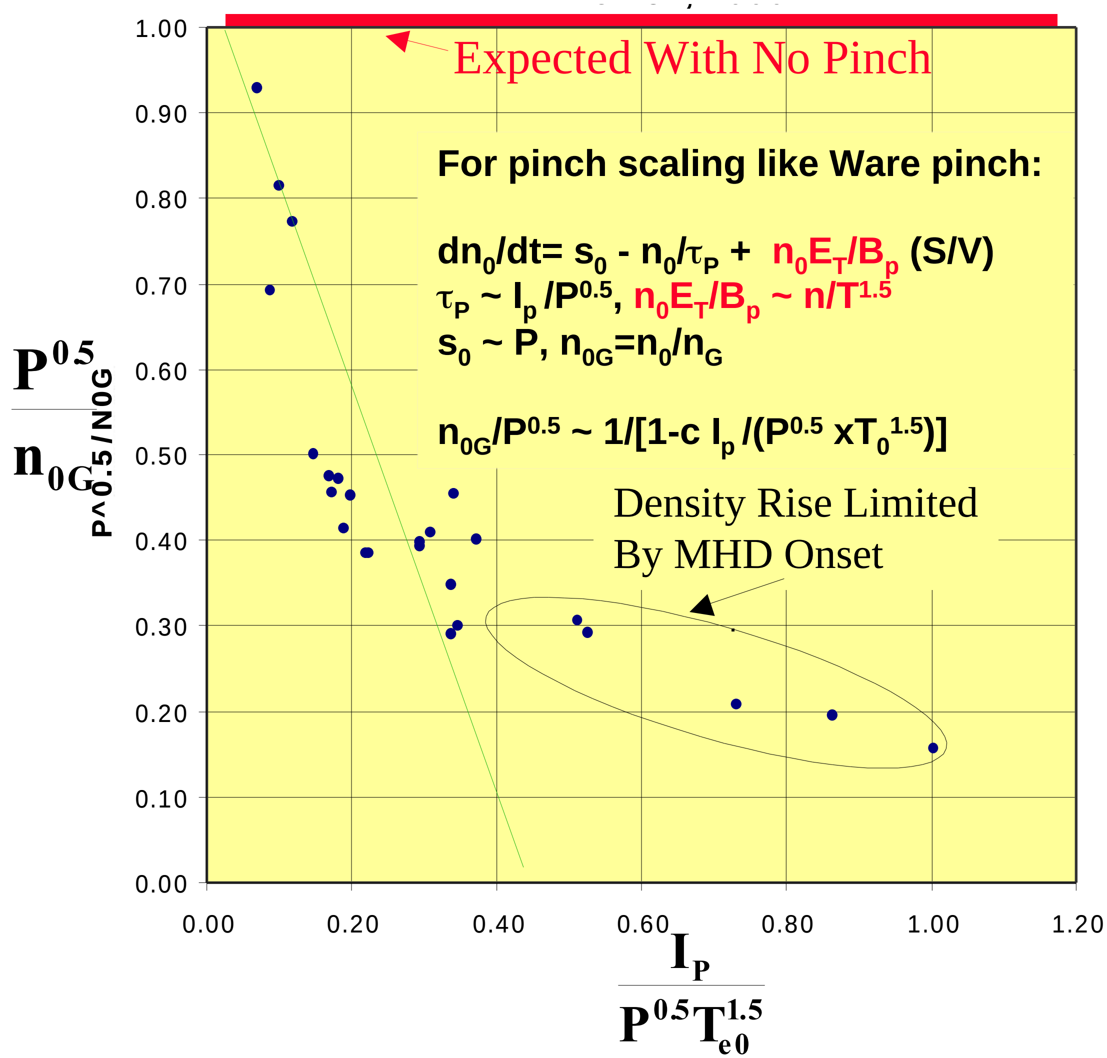
- Recovery of W at high density requires repeaking of density profile





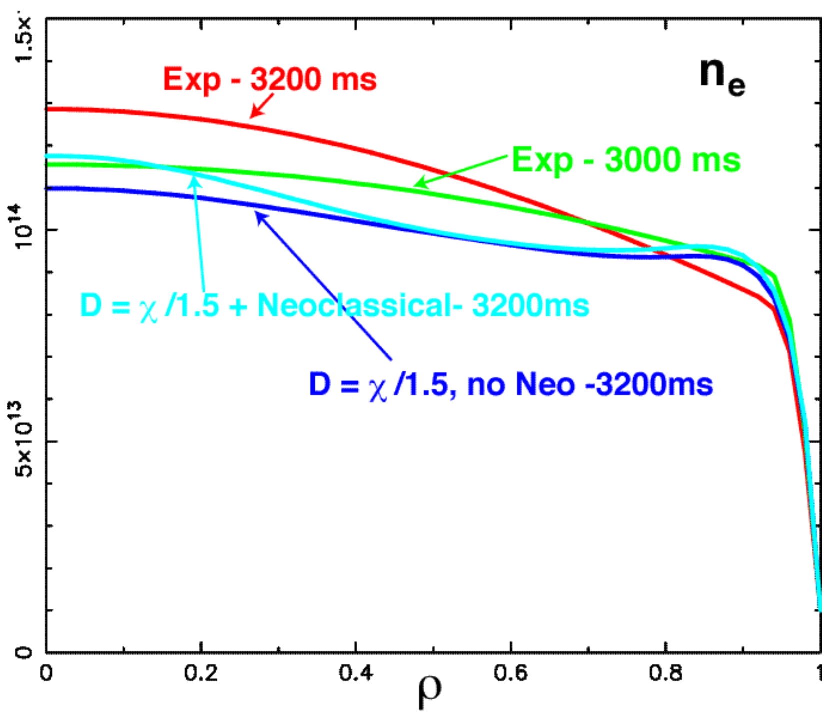
Density Peaking is Stronger Under Conditions that Reduce Central Temperature or Improve Central Confinement

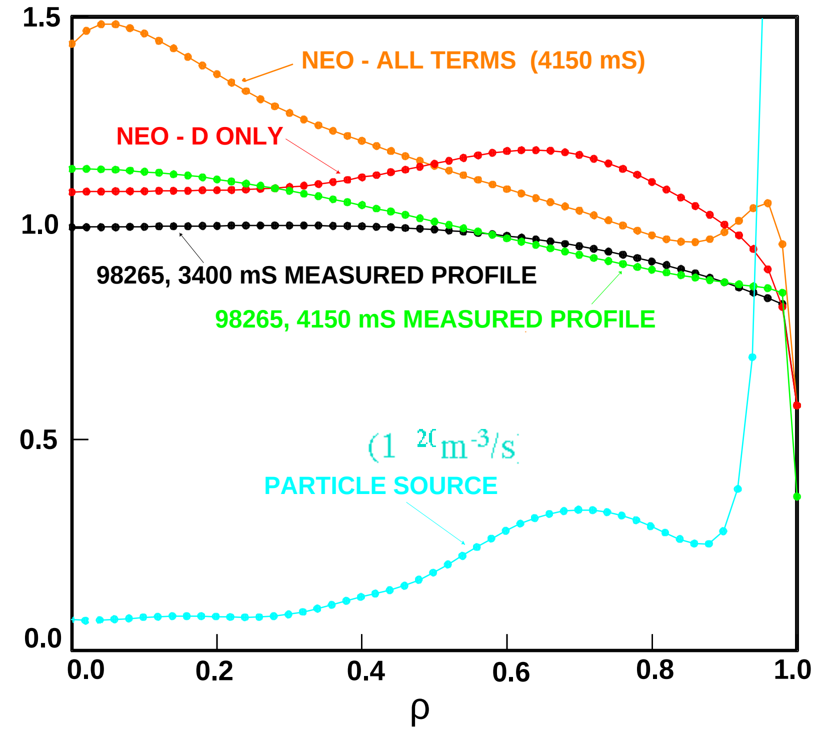
- Favorable for strong density peaking and high density with gas puffing:
  - Low heating power T_0 reduced and τ increased
  - Higher Gas Puff T_0 reduced through profile stiffness.
  - Low q T_0 reduced since temperature profile is less peaked at lower q.



Simulation of High Density Discharge Suggests Importance of Ware Pinch

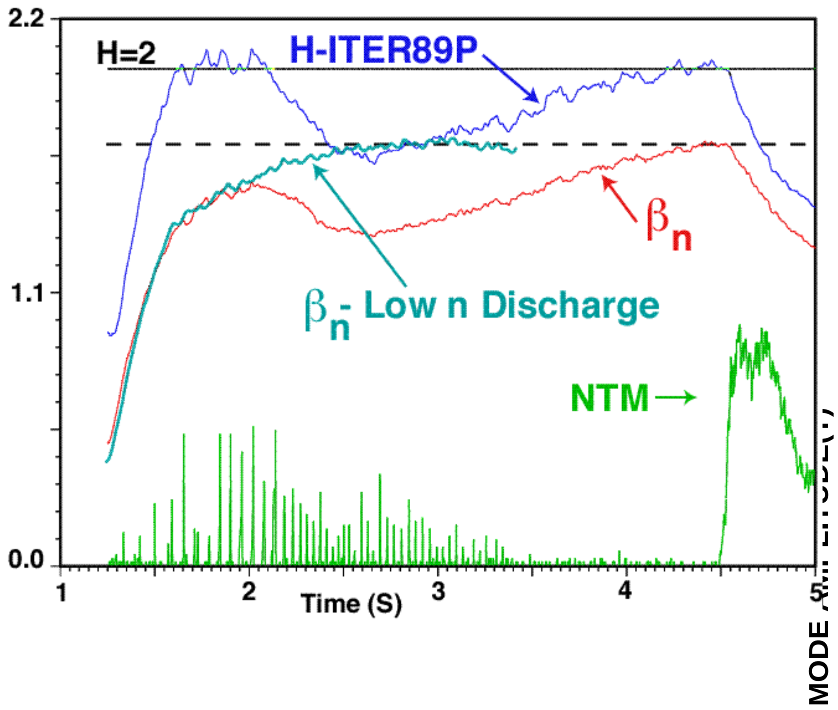
- Possibility that Ware pinch might account for central density rise was tested with transport simulation.
  - Pure neoclassical transport indicates Ware pinch is significant but overall transport is too small
  - D= χ/1.5 indicates Ware pinch is too small to account for central density rise but overall transport is too large.

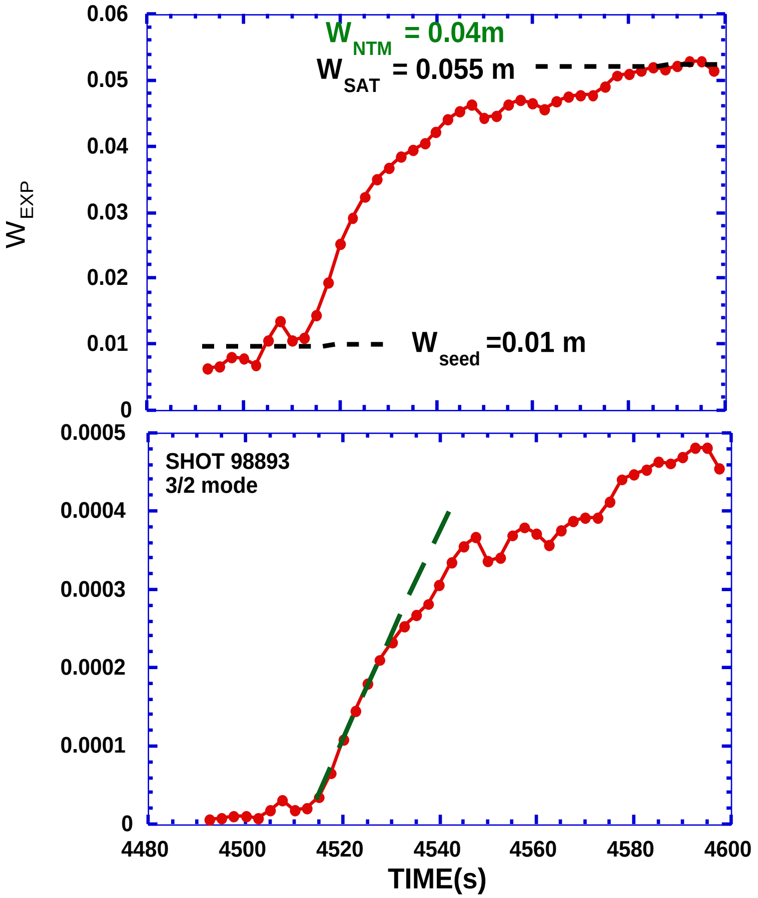




Termination of High Density Good Confinement Discharges is Consistent with NTM

- Termination of high n_e, high τ_E discharges is correlated with onset of MHD modes in the region between q=1 and q=1.5 at $1.4 < \beta_N < 1.8$.
- Linear growth and saturated width suggest neoclassical tearing Mode
- Trigger mechanism with rising mechanism remains is still unclear





Summary

- A large improvement in the product $H \times n/n_G$ was obtained in gas fueled discharges with divertor pumping: $H_{89P} = 2$ at $n/n_G = 1.4$.
  - Divertor configuration may allow higher pedestal density with gas puffing without high neutral density in the x-point region.
- H increased with density profile peaking, however peaking is typically similar to low density discharges.
  - Correlation of density peaking with low T_0 suggests Ware pinch.
  - Density peaking is required to offset loss of pedestal pressure resulting from a decrease in edge pressure gradient before Type I ELMs at high density.