Characteristics of H-mode Pedestals in Improved Confinement Regimes in DIII-D

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Presented at the
47th APS-DPP Meeting
Denver, Colorado

October 24–28, 2005

DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

Abstract

Characteristics of H-mode Pedestals in Improved Confinement Regimes in DIII-D,* R.J. Groebner, A.W. Leonard, T.C. Luce, C.M. Greenfield, G.L. Jackson, T.H. Osborne, D.M. Thomas, M.R. Wade, *GA*, M.E. Fenstermacher, *LLNL* – The characteristics of H-mode pedestals in improved confinement regimes are studied and compared to conventional ELMing H-mode discharges in DIII-D. These improved regimes include VH-mode, hybrid H-mode and Advanced Tokamak (AT) discharges. Initial results of this study show that across all regimes, 1) confinement improves as the pedestal electron beta-poloidal increases ; 2) the global beta-poloidal of the plasma is linearly related to the pedestal electron beta-poloidal; and 3) the scale length for the electron pedestal pressure profile is of similar magnitude. Thus, the initial results of this study show that there is a continuum of pedestal parameters with various confinement regimes falling within this continuum. In other words, the improved confinement in these regimes does not result from a dramatic change in pedestal characteristics.

*Work supported by U.S. DOE under DE-FC02-04ER54698 and W-7405-ENG-48.0

Motivation

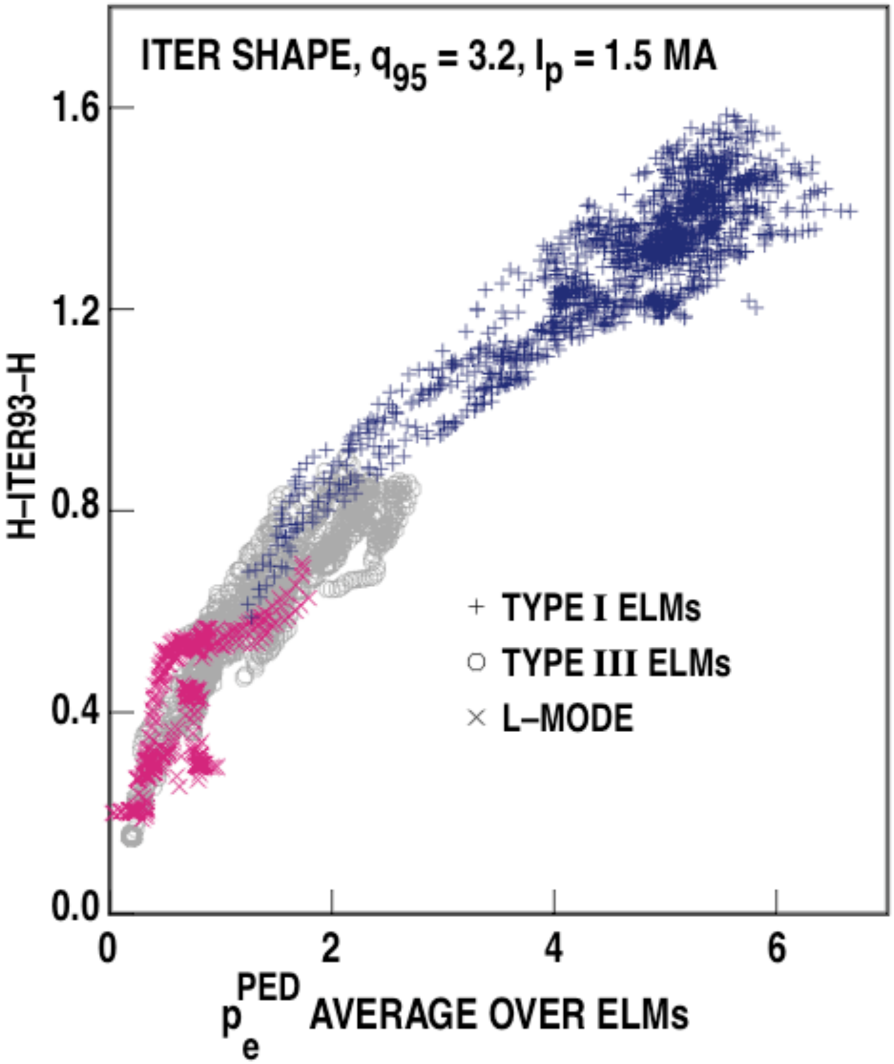
- **Osborne showed that H-ITER93H increased with p_e(ped) in standard H-mode discharges in original ITER shape**
- **What happens in improved DIII-D performance regimes**
  - VH-mode, Hybrid, Advanced Tok and QH-mode (ELM-free)
- **How does global performance correlate with pedestal?**
  - Core: Stored energy, H-factor, beta
  - Pedestal: Stored energy, pressure and beta
- **Are there differences in pedestal structure between confinement modes?**
  - Pressure scale length, η_e, barrier widths

Outline

- **Confinement enhancement factors as functions of pedestal pressure**
  - Mixed story: for a given regime, there is a trend for H to be independent of pedestal pressure
  - However, for a fixed pedestal pressure, different H factors are observed for different confinement regimes
- **Global stored energy and beta as functions of pedestal energy and beta**
  - General trend of global stored energy, β_{pol} and β_N to increase with pedestal counterparts
  - Correlation not perfect
- **Pedestal shape parameters**
  - Pressure scale length, η_e, barrier widths examined
  - No clear differences between various confinement modes

H-ITER93H Increases with Electron Pedestal Pressure in Original ITER Shape

(Osborne et al, Proc. 24th EPS meeting, Vol. 21A, (Euro. Phys. Soc., 1997) p. 1101)



- Trend for H-ITER93H to increase with p_e(ped)
- Strong correlation between global confinement and pedestal height
- There is some rollover at higher p_e(ped), not shown

Confinement Enhancement

What Can We Learn by Studying H-factor?

- **An H-factor shows observed confinement time divided by prediction from a scaling relationship**
- **If the scaling relationship correctly captures the scaling of a data set, then H-factor should be a constant as a function of a pedestal parameter**
- **If H-factor changes as function of a pedestal parameter, the scaling relationship is not capturing some physics in the observed confinement**
- **We examine several H-factors as functions of p_e(ped)**
  - For a given regime, there is tendency for H to be ~ constant as pedestal pressure is changed
  - However, for a fixed pedestal pressure, different H factors are observed for different regimes

Will Examine H-factors from 3 Confinement Scalings

- **ITER93E is a thermal ELMy scaling from D.P. Schissel, et al., 20th EPS Conf. on Controlled Fusion and Plasma Physics, Vol. 17C (1993) p. 103.**

$$\tau_{th}^{ITER93E} = 0.022 I^{0.76} B^{0.15} P^{-0.7} n_{19}^{0.42} M^{0.30} R^{2.30} a^{-0.30} \kappa^{1.05}$$

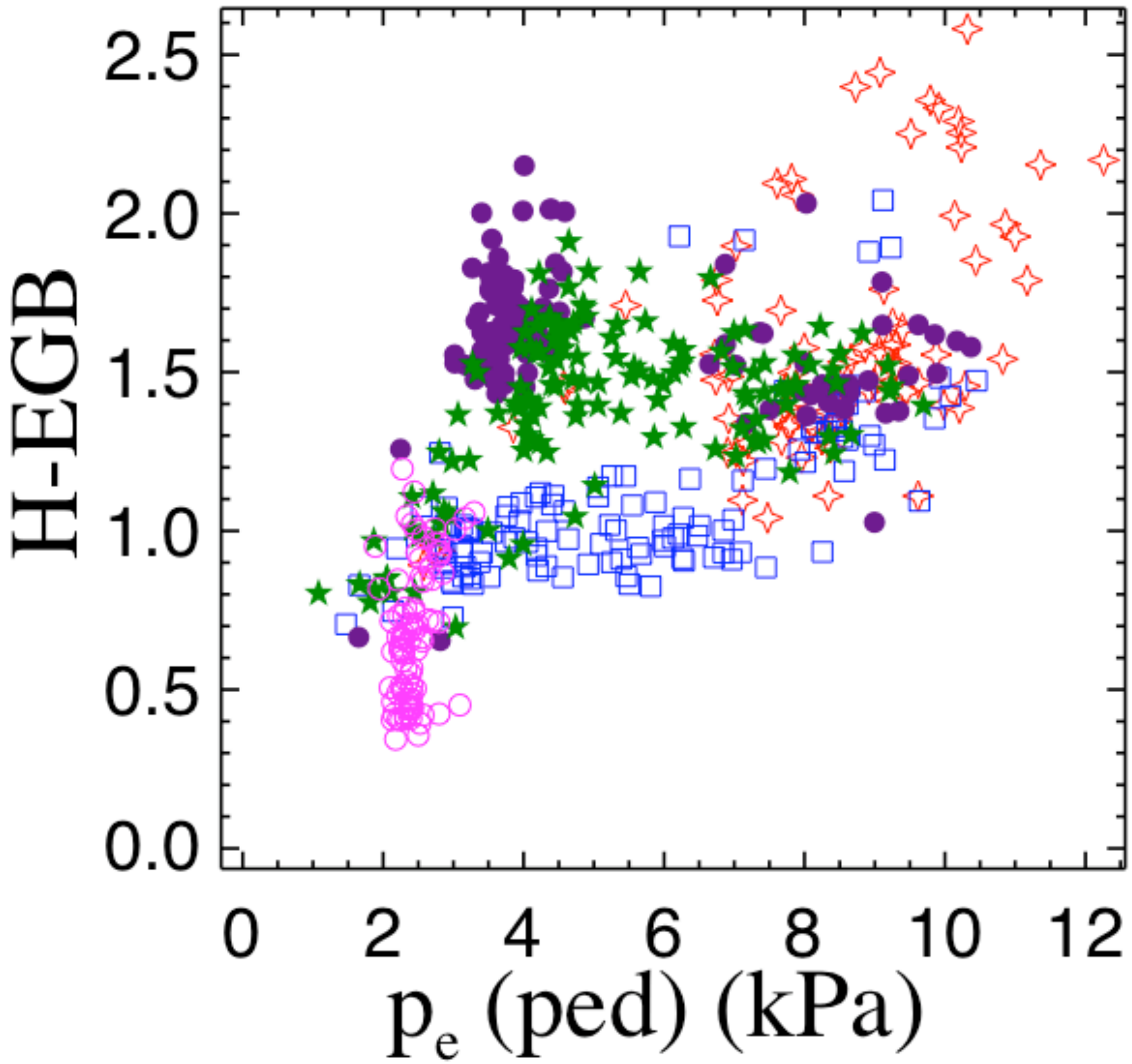
- **ITER89P is a scaling for total energy in L-mode from P.N. Yushmanov, et al, Nuclear Fusion, Vol. 30, 1999 (1990).**

$$\tau_{th}^{ITER89P} = 0.048 I^{0.85} B^{0.2} P^{-0.5} n_{20}^{0.1} M^{0.5} R^{1.2} a^{0.30} \kappa^{0.5}$$

- **EGB is an ELMy thermal scaling with electrostatic and gyrobohm constraints from C.C.Petty et el., Fusion Sci. Technol. , vol 43, 1 (2003)**

$$\tau_{th}^{EGB} = 0.028 I^{0.83} B^{0.07} P^{-0.55} n_{19}^{0.49} M^{0.14} R^{1.81} a^{0.30} \kappa^{0.75}$$

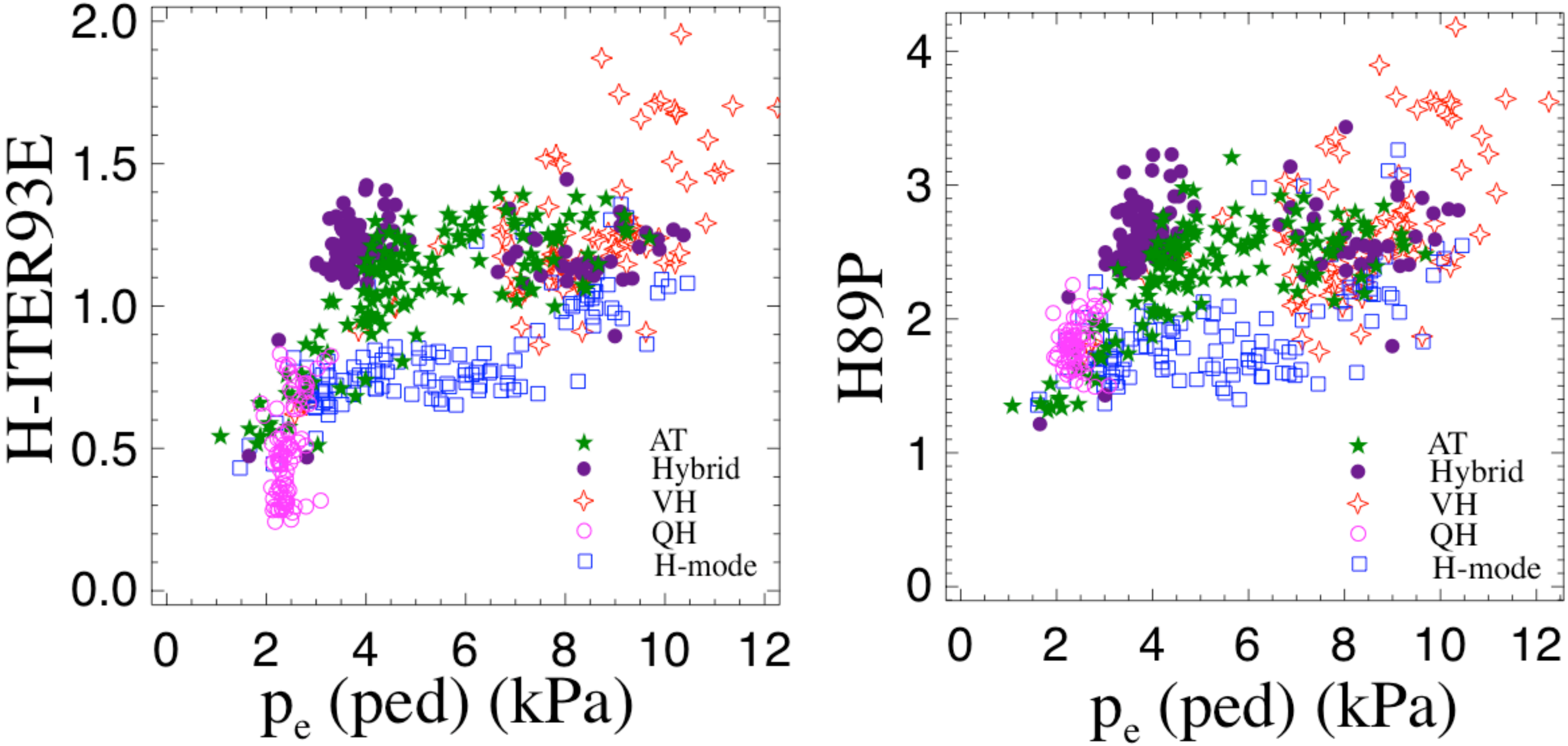
H-EGB Is Partially Correlated with Pedestal Height



- **H-EGB is confinement enhancement factor from an electrostatic, gyrobohm scaling**
  - Petty et al., Phys. Plasmas 11, 2514 (2004)
- **H-EGB is ~ constant versus p_e(ped) for H-mode, Hybrid and AT regimes**
- **There is also a trend for H-EGB to increase at a fixed p_e(ped) as the regime is changed**
- **QH-mode is different**

H-ITER93E and H89P Partially Correlated with Pedestal Height

Results are similar to those obtained for H-EGB

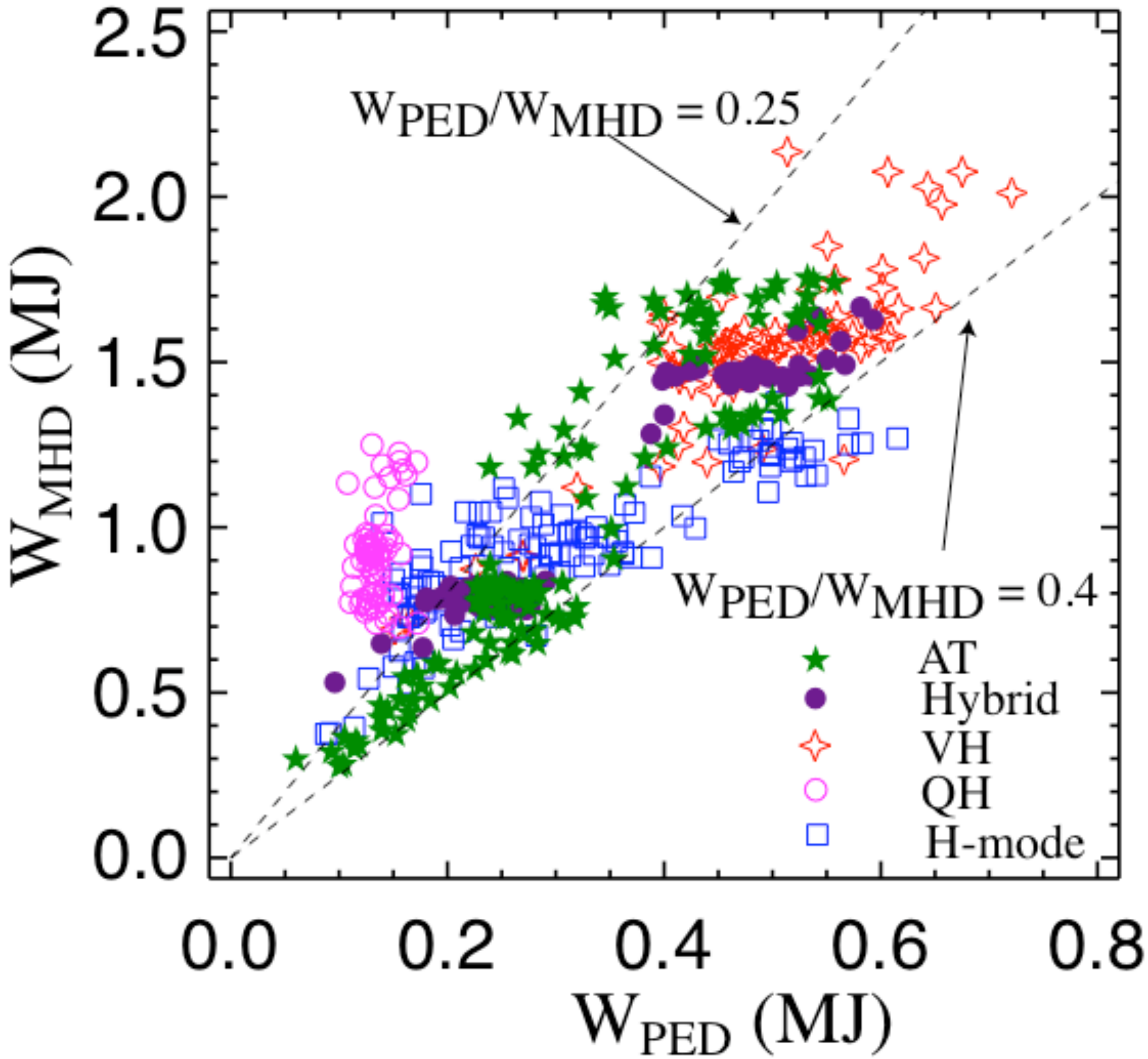


Stored Energy / Beta

Global Stored Energy and Beta Tend to Increase with Pedestal Energy and Beta

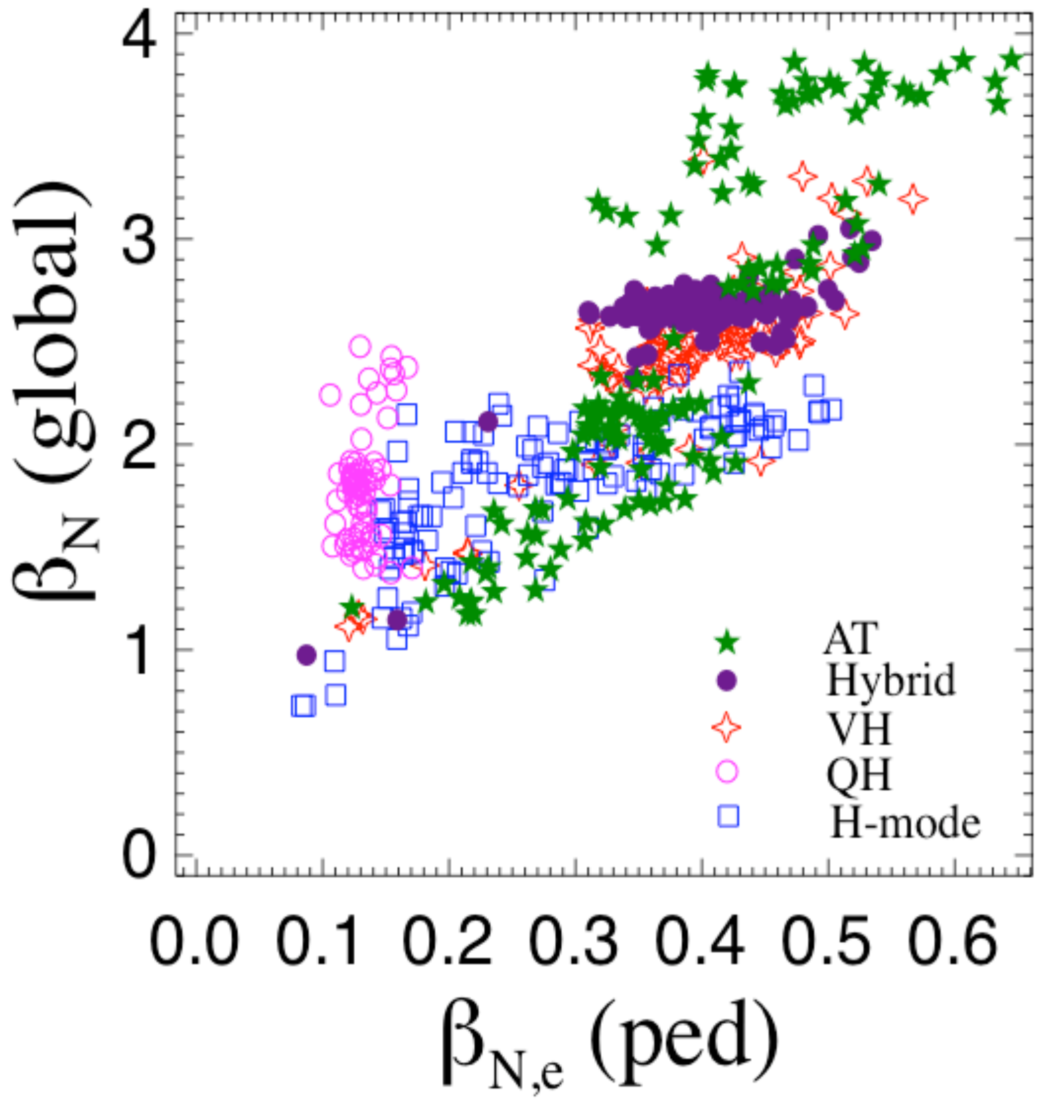
- **Overall, there is roughly a linear trend for global stored energy, β_N and β_{pol} to increase with their pedestal counterparts**
  - This can be interpreted as evidence for core performance depending on pedestal parameters
- **However, within a regime, particularly H-mode and Hybrid, global energy and beta parameters tend to be saturate despite increasing pedestal parameters**
  - Is this due to core MHD or other internal phenomena?
- **QH-modes are different - show increasing global energy and beta for fixed pedestal energy and beta**
  - Data are from a power scan, and core barriers form as power is increased, but pedestal is not changing much
  - Could be interpreted as evidence that ITB profiles are not “stiff”

Global Stored Energy Is Correlated with Pedestal Stored Energy



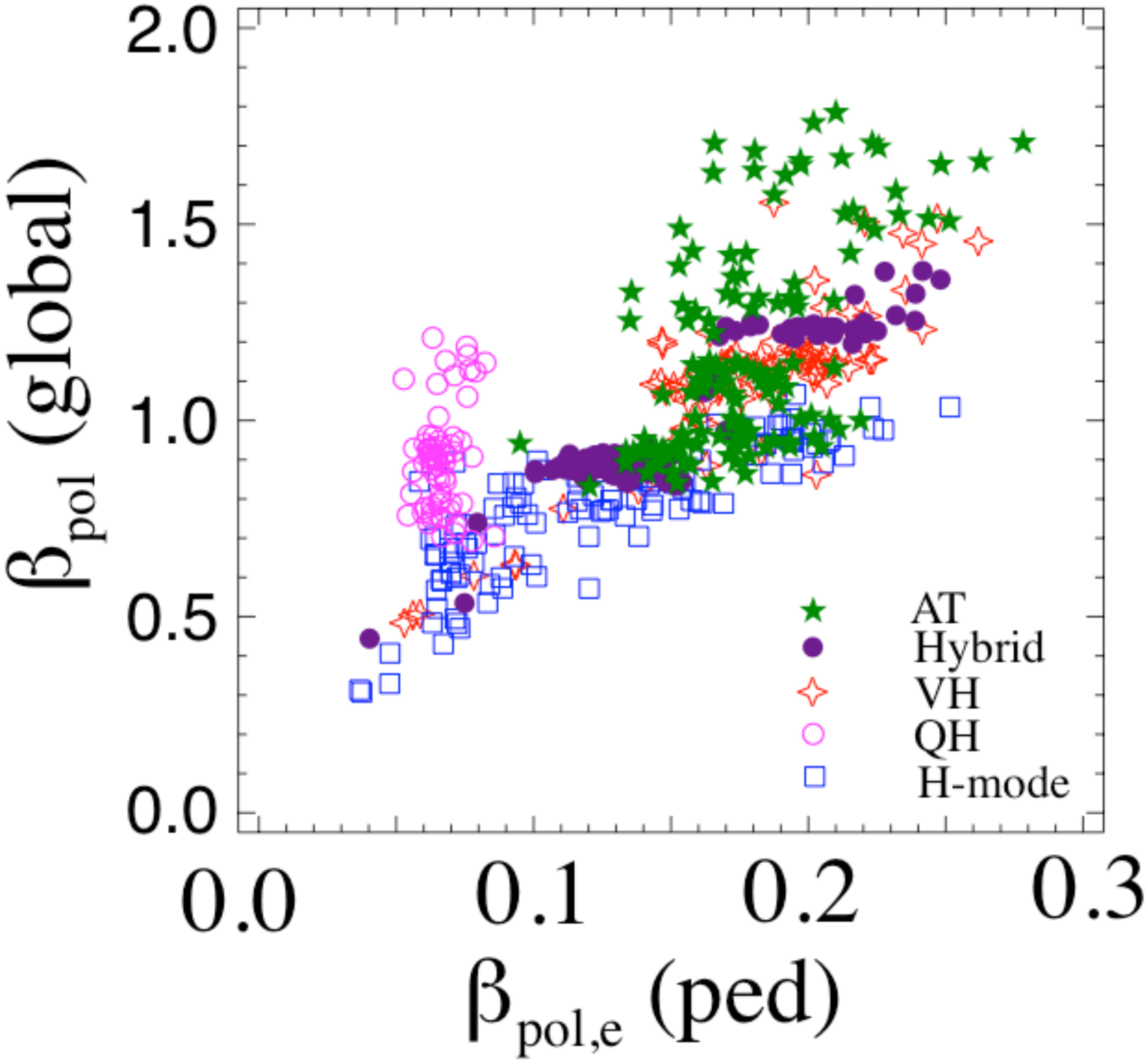
- **This is clearest evidence for pedestal height affecting the core**
- **Wped is stored energy in pedestal**
- **Obtained from 3/2 * pe(ped) *volume**
  - Ion pressure assumed equal to electron pressure
- **Over entire data set, there is roughly linear dependence between W_{MHD} and W_{ped}**
- **However, some regimes show saturation of W_{MHD} with W_{ped}**

Global β_N Tends to Increase with Pedestal $\beta_{N,e}$



- **Trend for global β_N to increase with pedestal $\beta_{N,e}$**
- **QH-mode shows global β_N increasing at constant pedestal $\beta_{N,e}$**
  - Data from a power scan

Global β_{pol} Tends to Increase with Pedestal $\beta_{pol,e}$



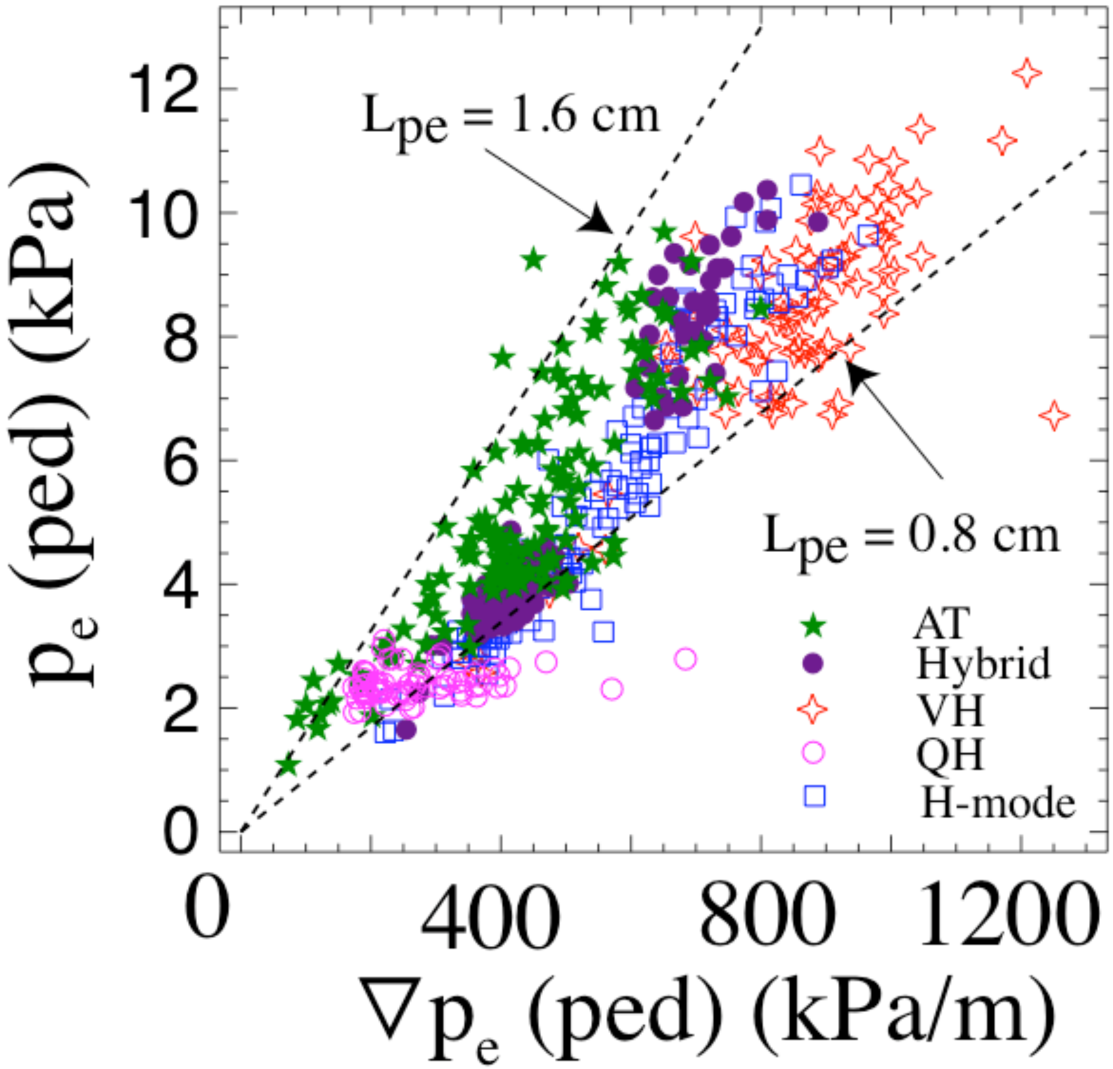
- Trend for global β_{pol} to increase with pedestal $\beta_{pol,e}$
- QH-mode shows global β_{pol} increasing at constant pedestal $\beta_{pol,e}$

Pedestal Shape

Examine Pedestal Structure Parameters

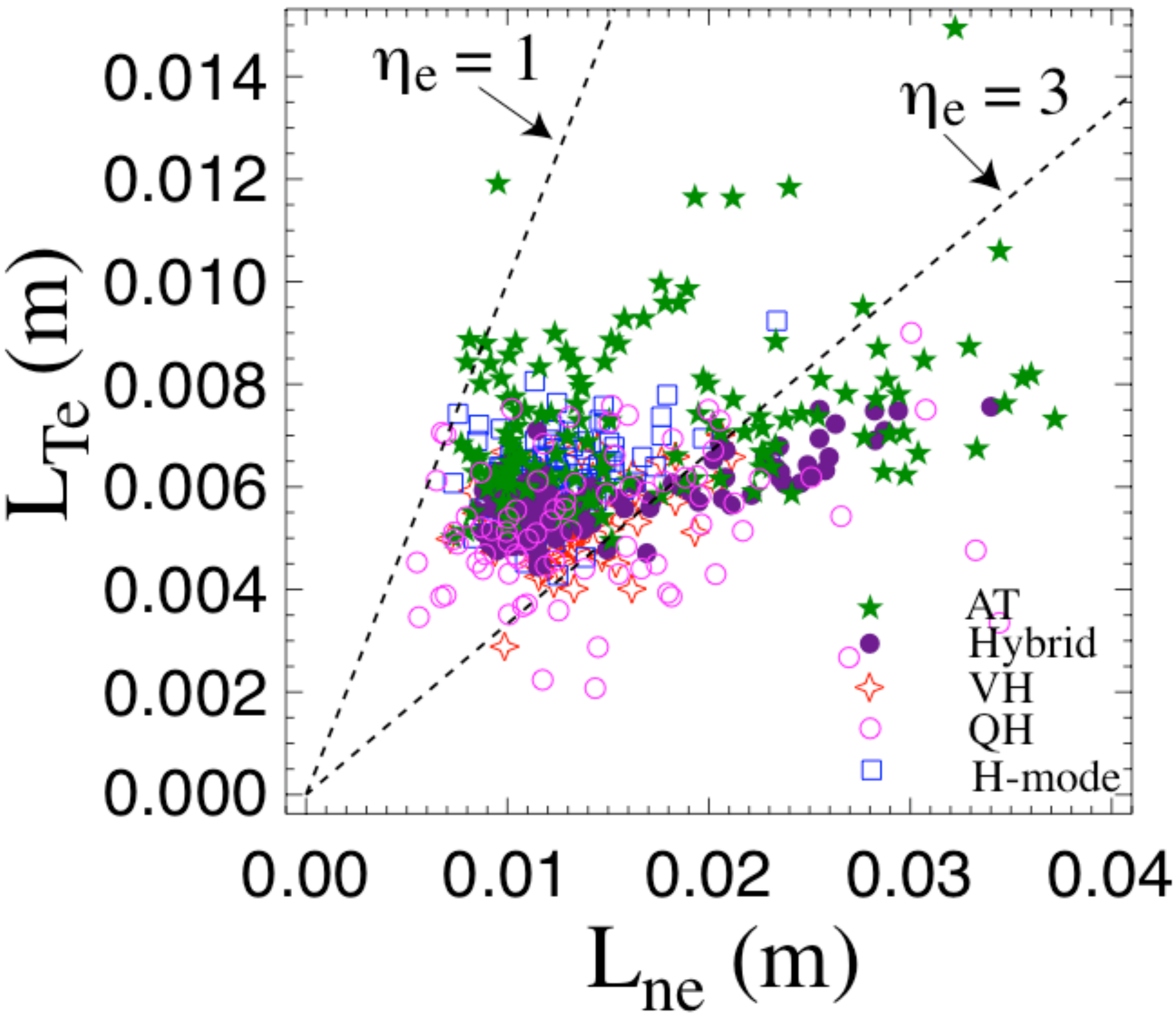
- **Are there differences in the pedestal structure between the different regimes?**
  - If so, that would be evidence that a regime depends on something special about the pedestal
- **How different are pedestal structure parameters?**
  - For instance, does pedestal "width" vary with regime
- **An initial survey of pedestal structure parameters finds no obvious differences between regimes**
  - The structure parameters include, electron pressure scale length, η_e and relation between n_e and T_e widths
- **Pedestal structure shows a continuum across regimes**

For All Regimes, Pressure Scale Lengths are in Range ~ 0.8 - 1.6 cm



- Pedestal p_e is roughly proportional to max pressure gradient
- This implies roughly constant pressure scale length for all regimes where $L_{pe} = p_e / \nabla p_e$
- L_{pe} in range 0.8 - 1.6 cm at outer midplane
- Note that VH-mode does not look different from other regimes

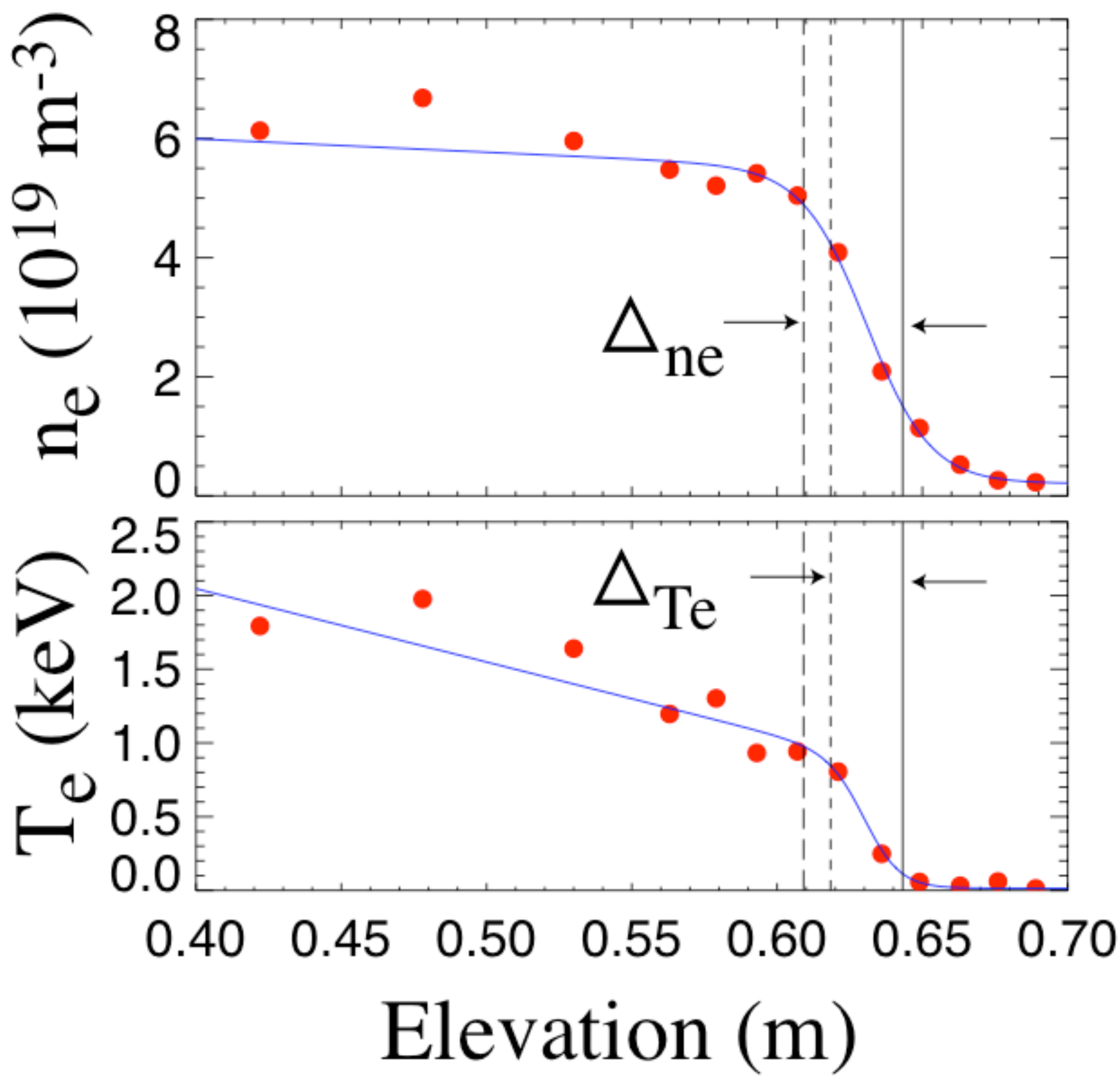
At Steepest Part of T_e pedestal, η_e Is ~ 1 - 3



- Electron density and temperature scale lengths fall in small range
  - $L_{ne} = n_e / \nabla n_e$
  - $L_{Te} = T_e / \nabla T_e$
- The ratio of these scale lengths is η_e where

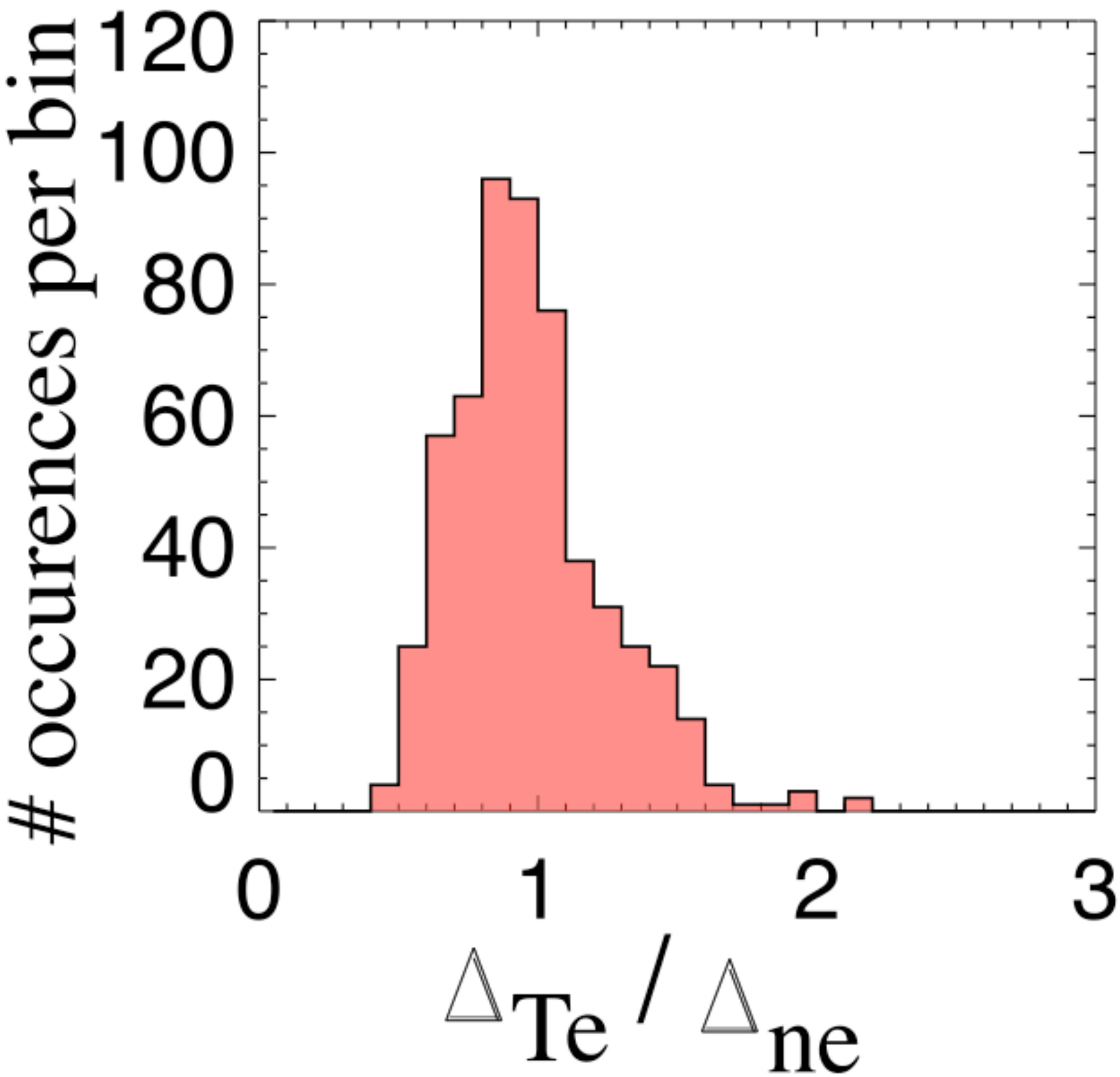
  $\eta_e = L_{ne} / L_{Te}$
- Most values of η_e are in range 1-3
- No regime stands out
- Some data at high η_e are few ms after ELMs

Widths defined from foot of T_e barrier



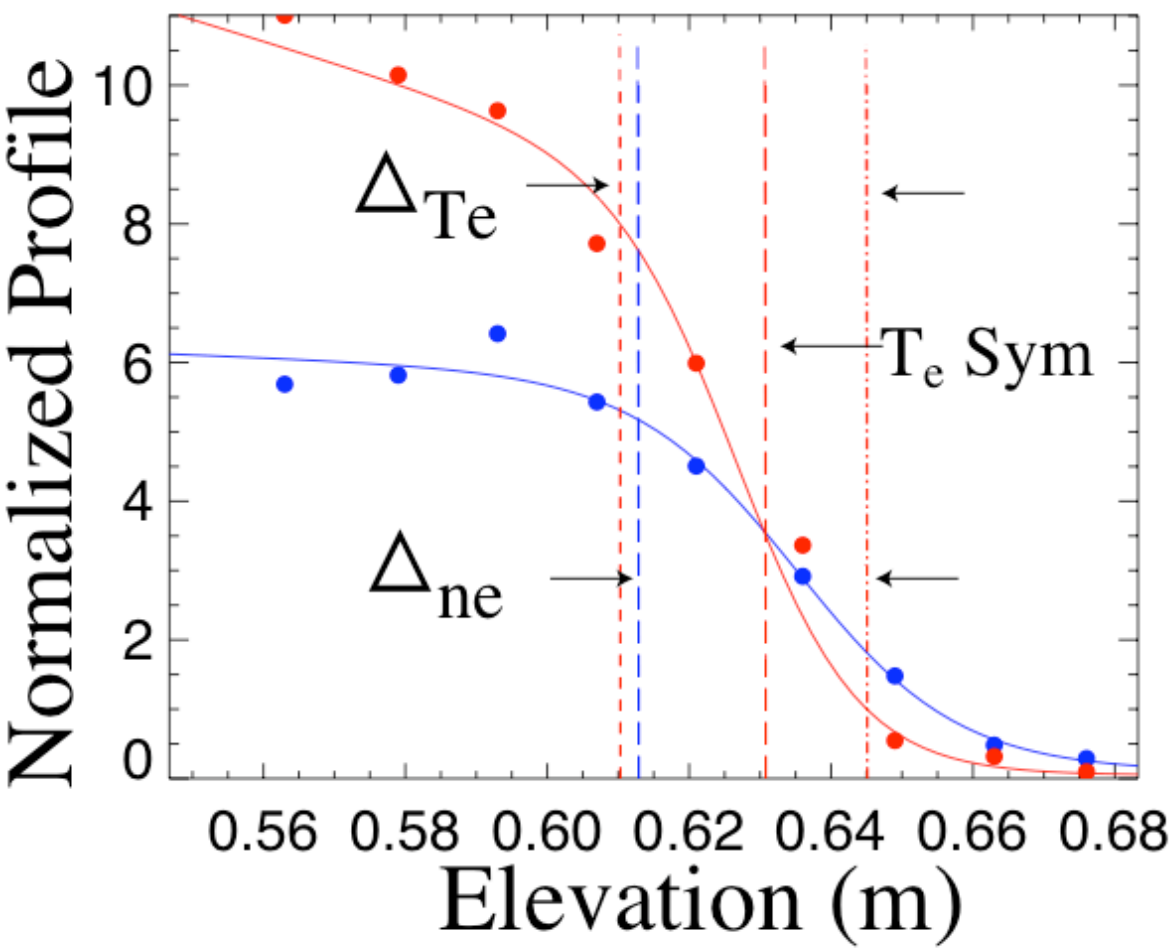
- **Convenient way to define density width is to reference it to foot of T_e barrier**
- **In that way, the widths Δ_{ne} and Δ_{Te} are referenced alike**
- **Then, Δ_{ne} and Δ_{Te} give measure of which barrier extends further into plasma**
- ***This is not how newid is defined in Tanhfit!!!***

T_e and n_e Barrier Widths Are Comparable



- For all data in the study, most probable ratio of widths is one.
- That implies that both barriers tend to penetrate about same distance into plasma
- Similar to results from ELMing H-modes

Widths and Scale Lengths are Not Necessarily Identical



- **Data shown for T_e (red) and n_e profiles (blue) with nearly identical widths**
  - *Width measured from foot of T_e profile*
- **Profiles are normalized to be equal at T_e symmetry point**

  Point of max gradient
- **However, normalized gradients differ by factor of about two**
  - Due to fact that full width of the density step extends into SOL

Conclusions - 1

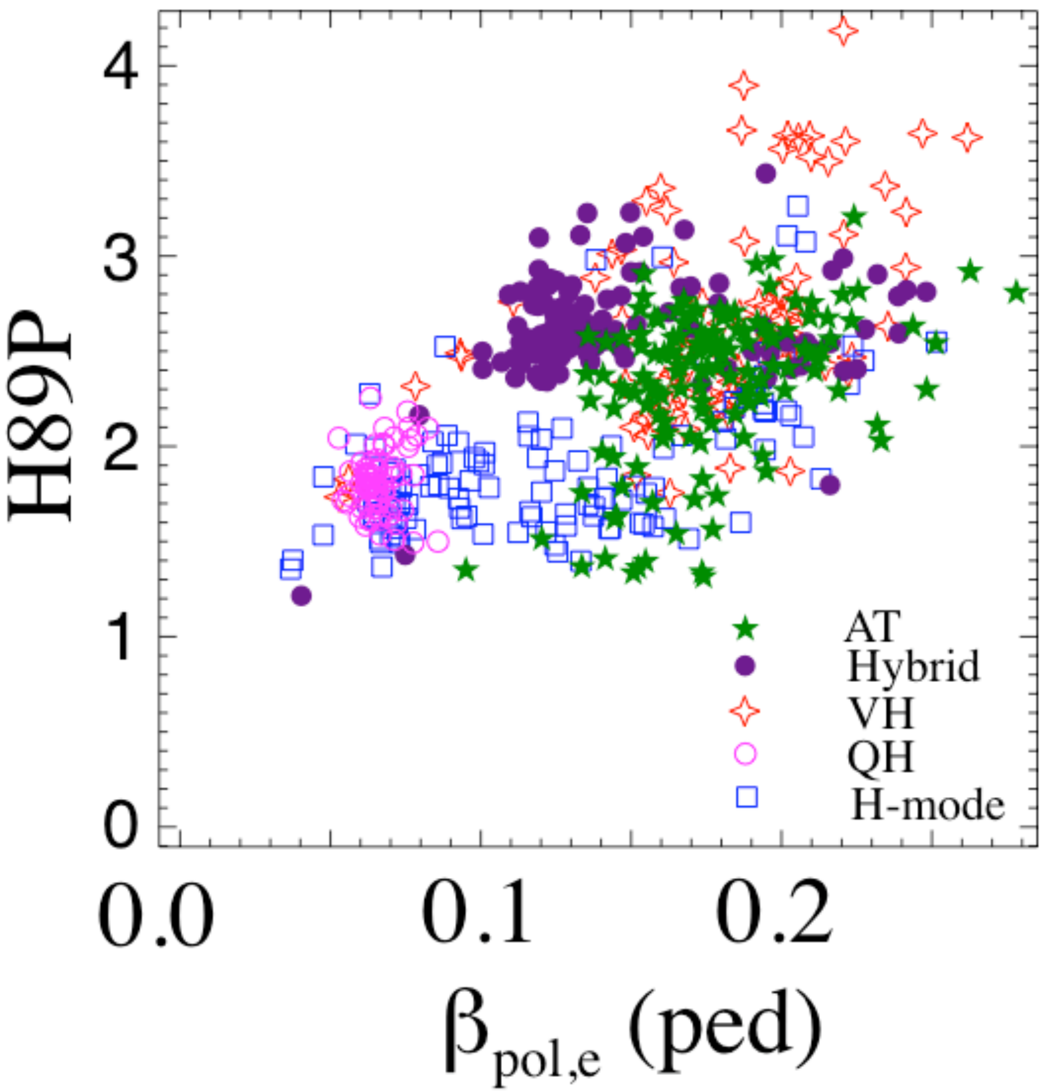
- **Standard core confinement scalings capture variation of confinement time as pedestal pressure is varied**
  - i.e., H is roughly constant as pedestal pressure varies
- **However, there are improvements in confinement which cannot be attributed to pedestal**
  - Most likely, shape, core MHD, pressure profiles, etc are important
- **There is a general trend for global energy and beta to increase with pedestal energy or beta**
  - This is best evidence for dependence of core performance on pedestal parameters
  - However, within given regimes, this trend can be violated
    - Standard H-mode and hybrids show global beta being constant with increasing pedestal beta
    - QH-mode shows global beta increasing at constant pedestal beta

Conclusions - 2

- **There are no clear differences in pedestal shape parameters between confinement modes**
  - Thus, the various regimes do not appear to depend on special pedestal features
  - There is a continuum in pedestal parameters, particularly pressure and pressure gradient, between the regimes

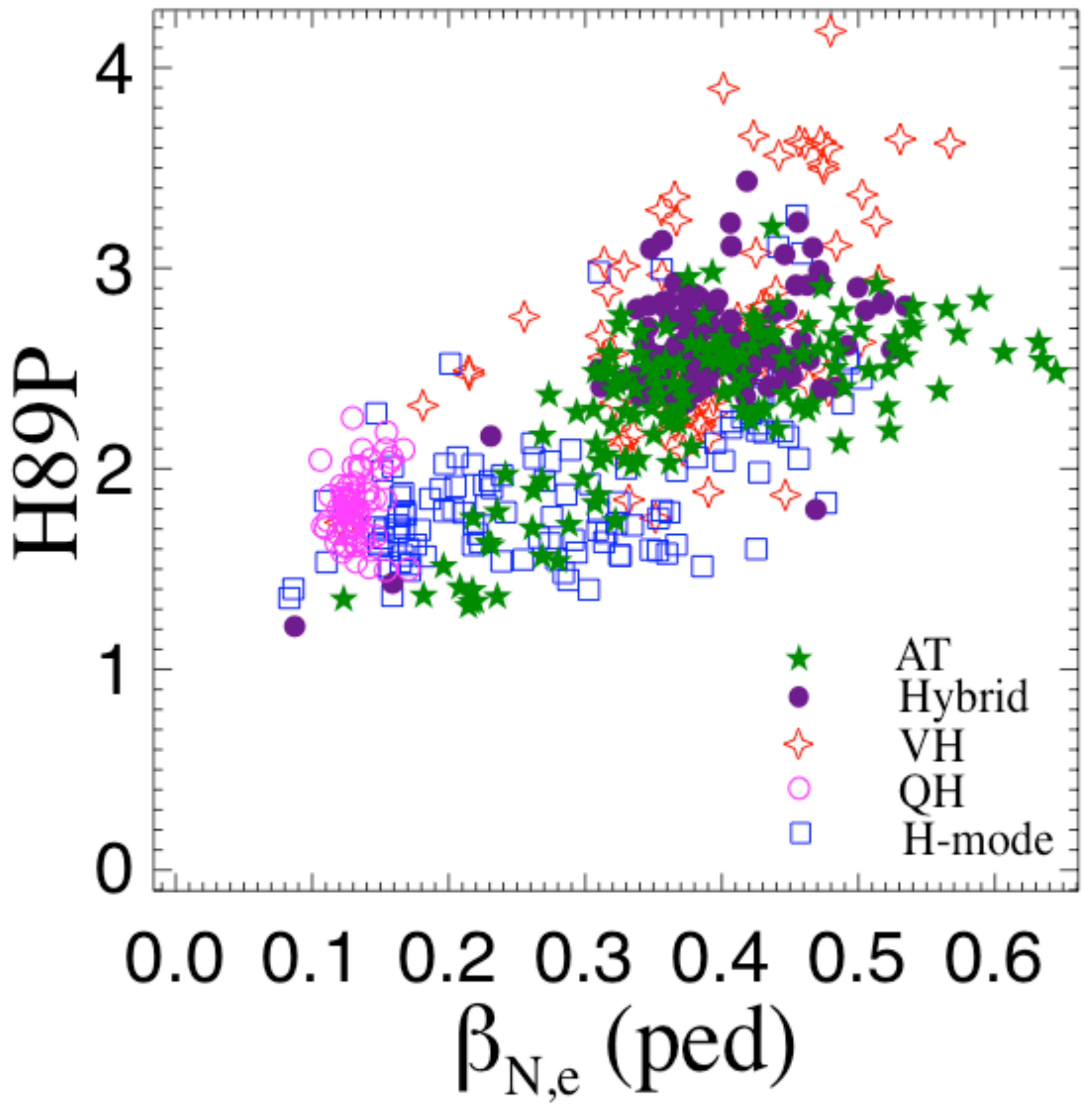
- **There is a lot more to be done**
  - In particular, ion pedestal parameters need to be examined

H_{89} vs pedestal electron β_{pol}



- **For a given regime, H89P is mostly flat in $\beta_{pol,e}$(ped)**
- **Between regimes, there is tendency for H to vary with $\beta_{pol,e}$(ped)**
- **Highest H89P observed near highest $\beta_{pol,e}$(ped)**

H_{89} vs pedestal electron β_N



- For a given regime, H89P is mostly flat in $\beta_{N,e}$(ped)
- Between regimes, there is tendency for H to vary with $\beta_{N,e}$(ped)
- Highest H89P observed near highest $\beta_{N,e}$(ped)

Summary: Correlation of H-factor and Pedestal Electron Pressure/Beta

- **For H-mode, Hybrid and AT data in this dataset, all H factors are relatively independent of either pedestal electron pressure or beta**
  - Thus, these confinement scalings capture variation of an energy confinement as pedestal is changed
- **However, for fixed pedestal electron pressure or beta, the H factors can increase as we move to better confinement regimes**
  - Thus, these confinement scalings do not capture all differences between the regimes. Other physics must be invoked.
- **Highest H-factors observed in transient phase of VH-mode**
- **H-ITER93E and H-EGB do not properly capture confinement scaling in QH-mode**