Scaling of the H-Mode Pedestal and ELM Characteristics with Gyro-Radius on the JET and DIII-D Tokamaks

by

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with

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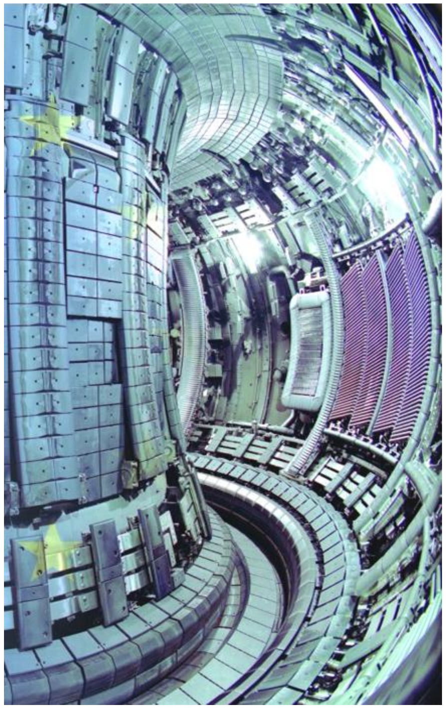
DIII-D

JET



EFDA JET

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GENERAL ATOMICS

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Goals of the Experiments

- **Determine the scaling of the edge transport barrier (ETB) width, *w/a*, and ELM size with normalized gyro radius, $\rho_* = \rho/a$.**
  - Since ρ_*^{ITER} < current tokamaks ($\rho_*^{ITER}/\rho_*^{JET}<0.5$)$\Rightarrow$ $w/a \propto \rho_*^X$, $X>0$ is undesirable for ITER ($Q \sim T^{PED}$)
    - $X>0$ suggested by some theoretical arguments and experiments: V_{ExB} turbulence suppression: $\gamma_{DW} \sim c_s/a = (V_{ExB})' \Rightarrow w/a \sim \rho_*^{1/2}$
  - Vary ρ_* keeping β, υ_*, q, T_e/T_i, M, plasma shape fixed $\Rightarrow \rho_* \propto (aB^{4/5})^{-5/6}$
- **Examine the role of the edge particle source in ETB structure and ELMs**
  - With all pedestal dimensionless parameters matched
    "plasma physics" $\Rightarrow w \propto a$
    neutral source $\Rightarrow w = \lambda_n \propto 1/n \propto a^2$

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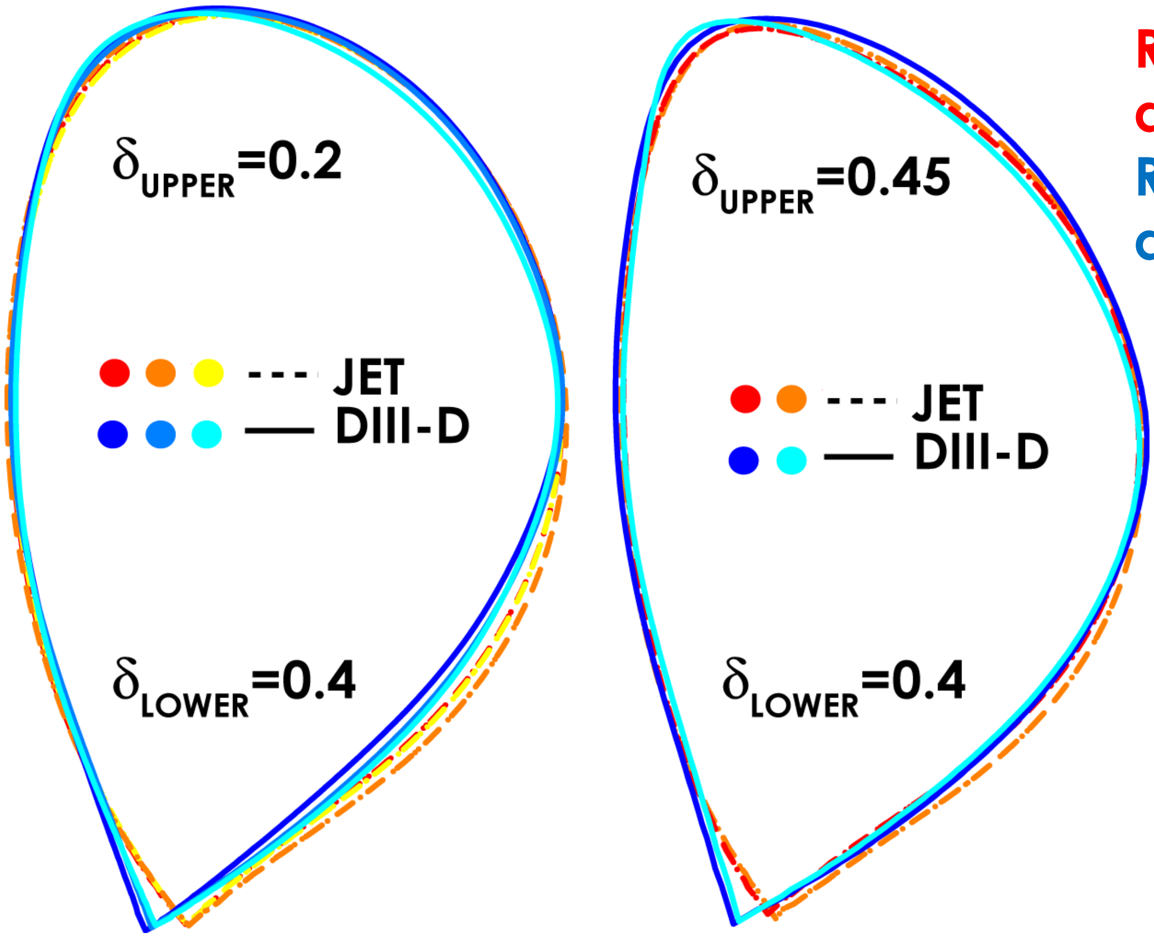
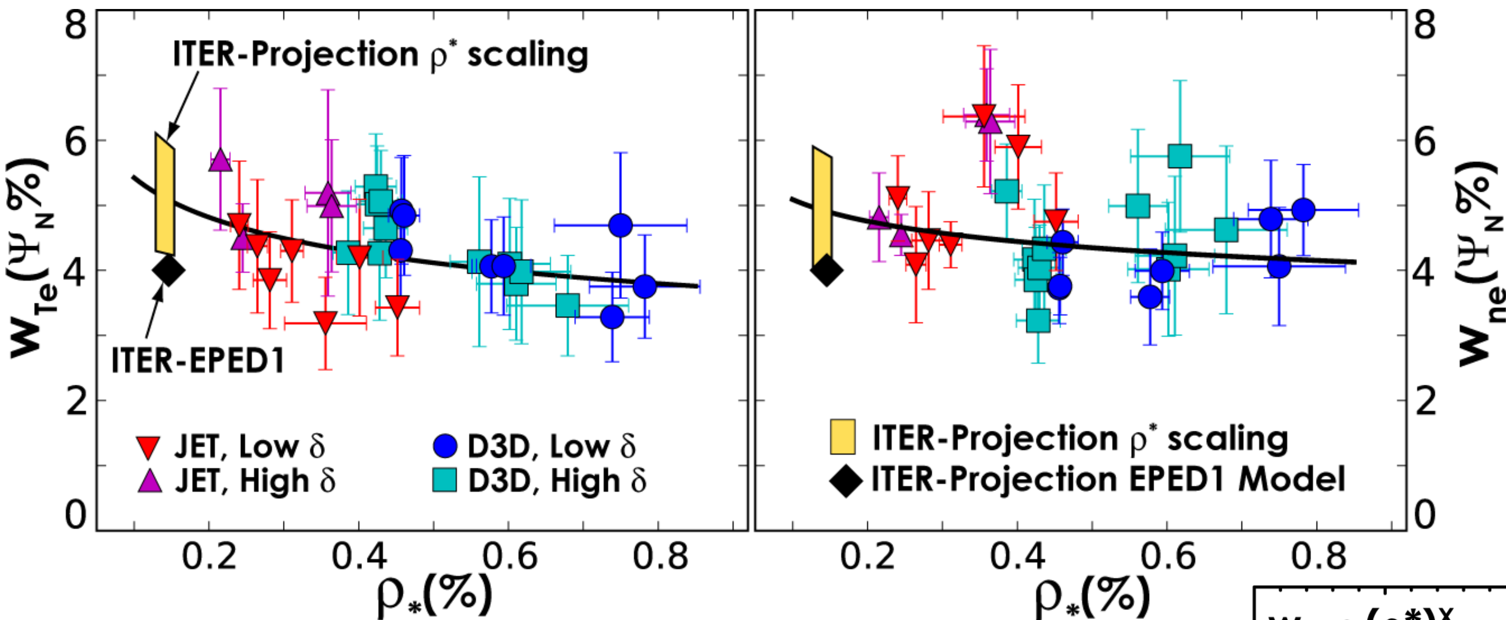
ρ_*^{PED} Scans Carried Out in Both High and Low Triangularity Shapes



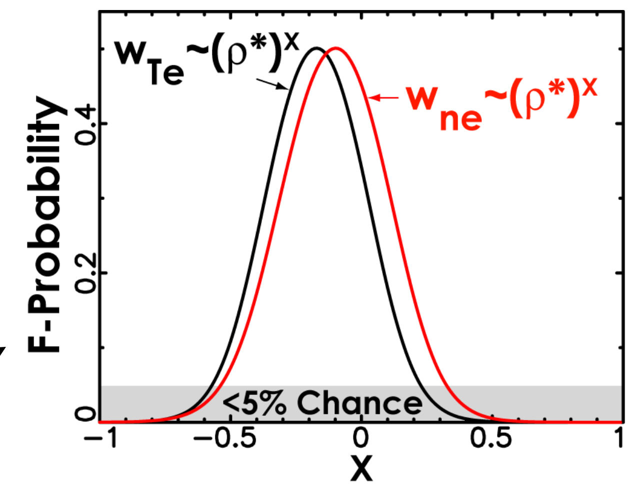
R_{JET} = 2.95m,
a_{JET} = 0.95m;
R_{D3D} = 1.67m,
a_{D3D} = 0.54m

- **Shapes normalized to major radius, R**

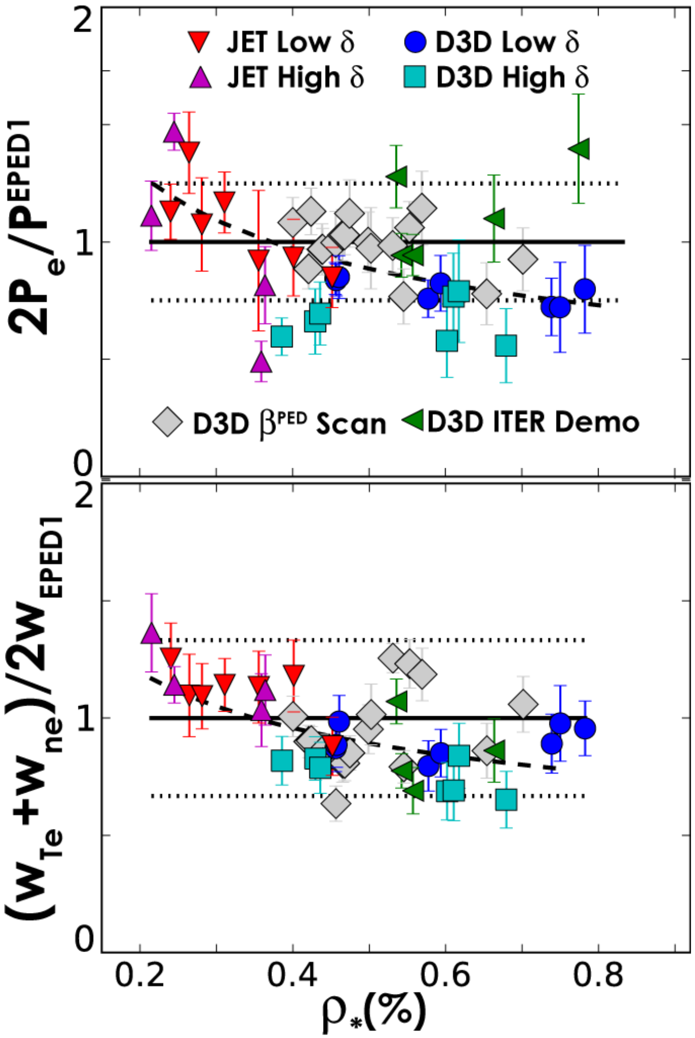
Both n_e and T_e Widths are Relatively Unchanged Over the Factor of 4 Range of ρ_*



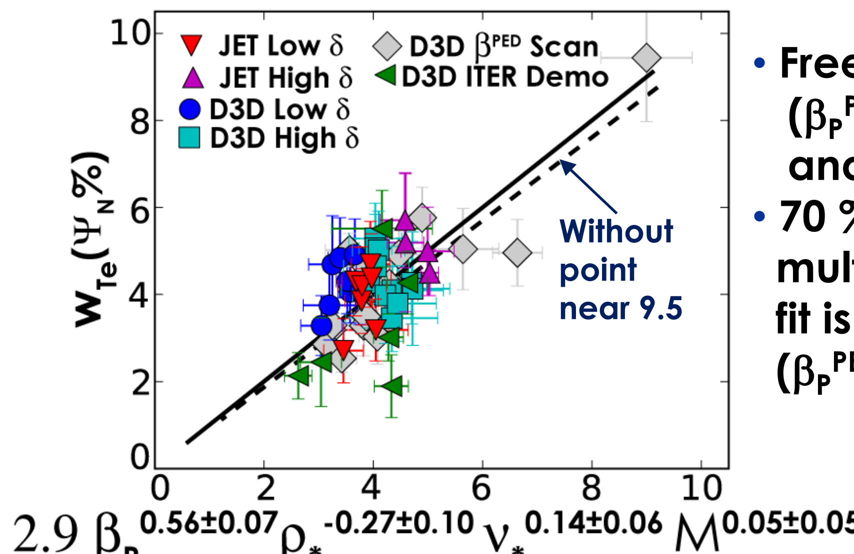
- Fits of w in normalized poloidal flux, ψ_N, give weak inverse dependence on ρ_*
  $w_{Te}(\psi_N\%) = (3.65\pm0.27)(\rho_*(\%))^{-0.17\pm0.08}$
  $w_{ne}(\psi_N\%) = (4.06\pm0.34)(\rho_*(\%))^{-0.10\pm0.08}$
- Low probability of significant positive ρ_* scaling
  - $w_{Te} \propto \rho_*^X$ where X>0.22 is < 5%, X>0.10 is < 20%
  - $w_{ne} \propto \rho_*^X$ where X>0.32 is < 5%, X>0.17 is < 20%



Comparison with EPED1 Model (Snyder[1] TP8.00018) Suggests a Residual Inverse ρ* Dependence



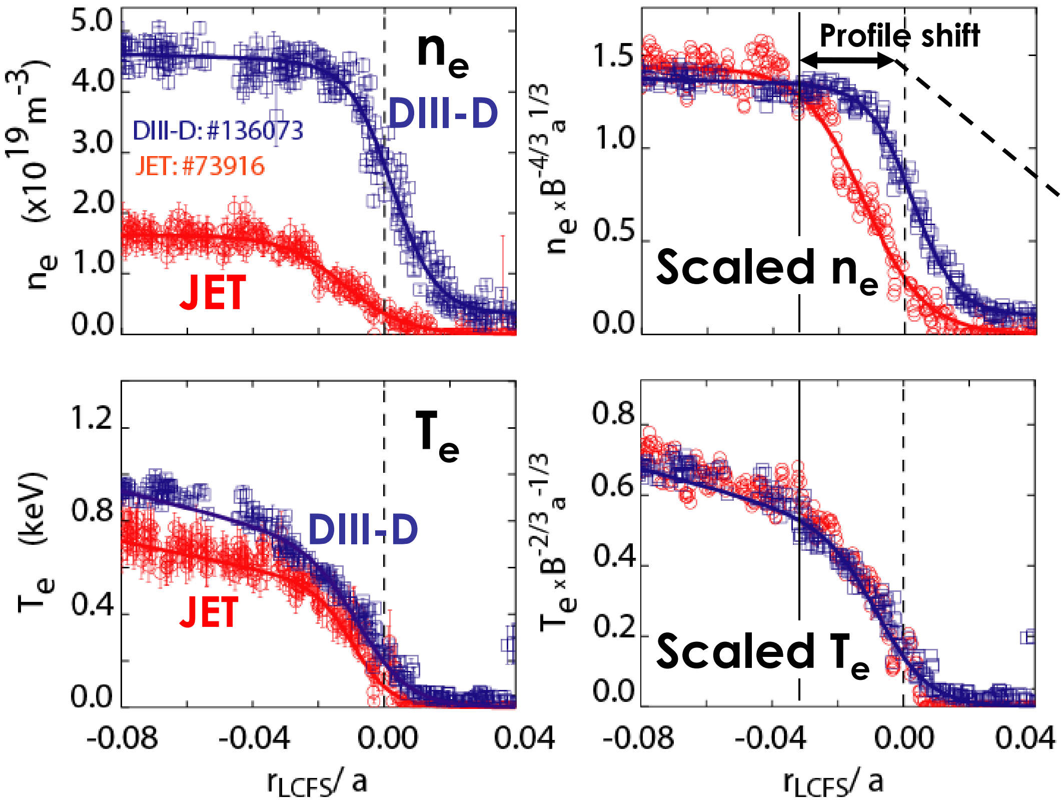
- **EPED1 model combines KBM width scaling $w(\psi_N) \propto (\beta_P^{PED})^{1/2}$ with PB mode stability constraint to determine *w* and P_{PED} self consistently**
  - Fits data from several Tokamaks
- **ρ* scan discharges suggest a residual ρ* dependence**

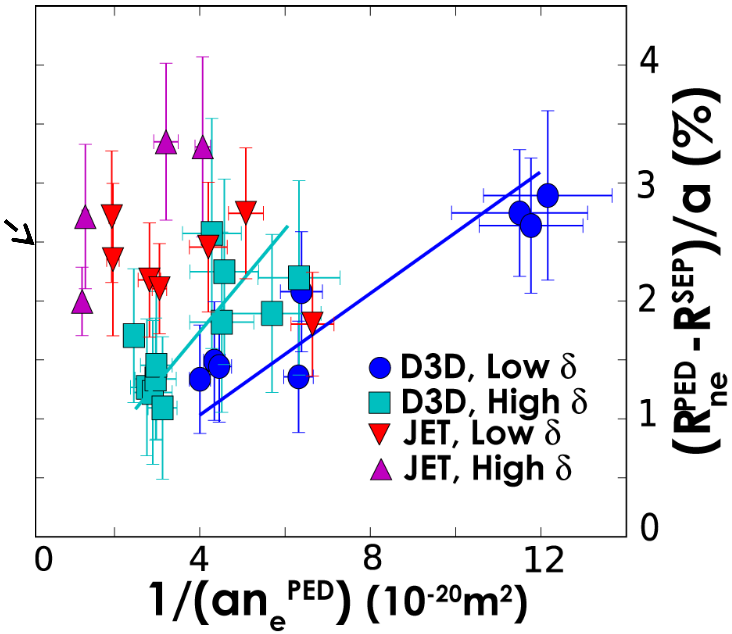


- **Free fit recovers $(\beta_P^{PED})^{1/2}$ scaling and gives $\sim\rho_*^{-1/4}$**
- **70 % chance multi-parameter fit is better than $(\beta_P^{PED})^{1/2}$ alone**

[1]P.B. Snyder Phys. of Plasmas, 16, (2009)

T_e Profiles Match with all Dimensionless Parameters Matched but n_e Profiles Suggest Particle Source Effect





- Top of n_e pedestal shifts inward as MFP, $\lambda_n / a \propto 1/(an_e)$, increases on D3D
- Trends offset at different δ on D3D
- JET has larger normalized shift and no obvious n_e dependence

- At dimensionless parameter match
  - T_e profiles matched
  - n_e profile in DIII-D discharge is shifted outward relative to T_e profile

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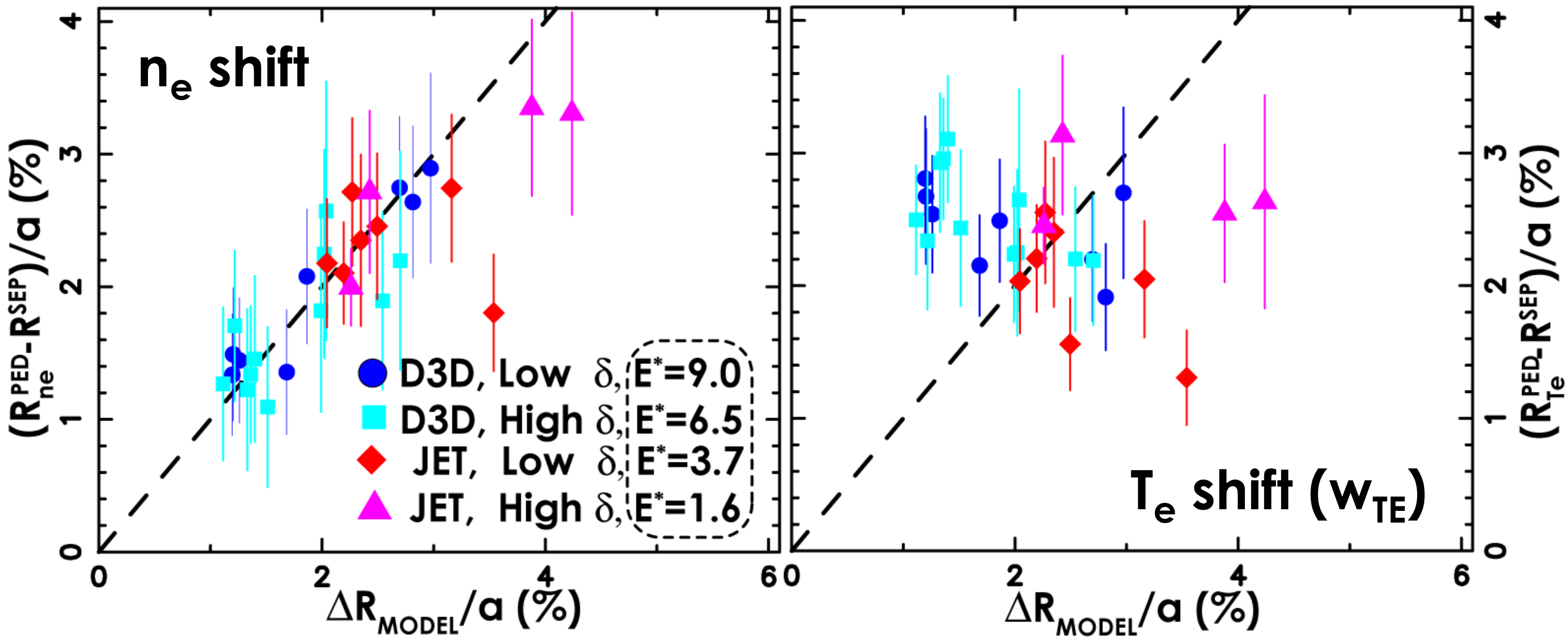
Variation in n_e Profile Shift with δ and Tokamak Suggests Variation in Poloidal Distribution of Neutral Source

- **Engelhardt-Mahdavi model[1,2]:** $\lambda_n / a \propto 1/(E^* a n_e)$

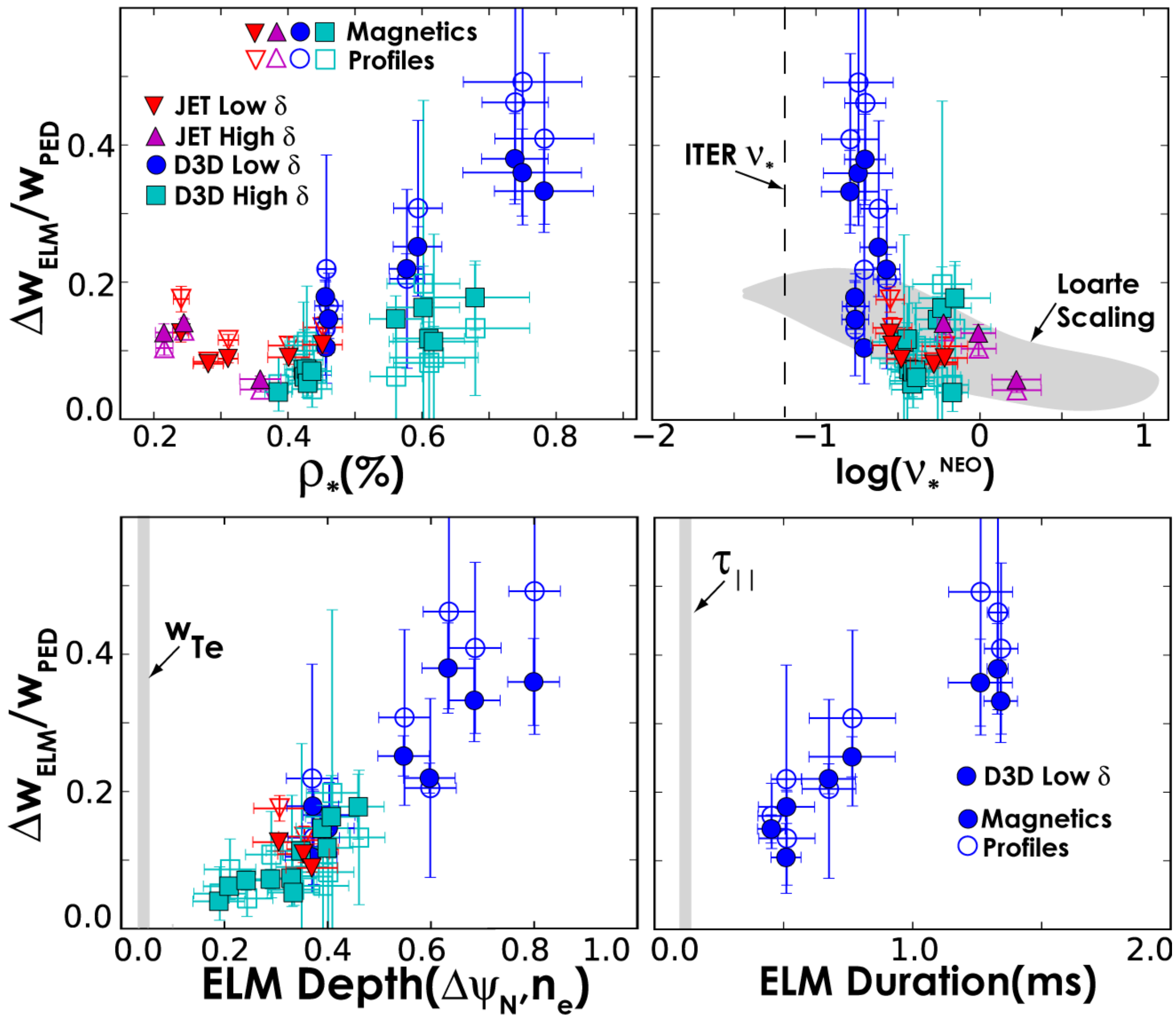
$$E^* = \left(\oint n_0 |\nabla \psi|_{MIDPLANE} / |\nabla \psi| dl\right) / \left(\oint n_0 / dl\right)$$

  - T_i^{SEP} and Franck-Condon neutrals



[1]W. Engelhardt, W. Fenenberg, J. Nucl. Mater. **76-77** (1978) 518
[2]M.A. Mahdavi et al., Plasma Phys. **10** (2003) 3988.

ELM Losses Increase Strongly with ρ_* on DIII-D but not on JET



- ELM losses increase strongly with ρ_* on DIII-D
- Losses match at identity point but trend with ρ_* weakly reverses in JET
- ELM loss at high ρ_* on DIII-D exceed value expected from υ_* scaling
- Large ELM loss at high ρ_* on DIII-D are correlated with increased ELM depth and duration

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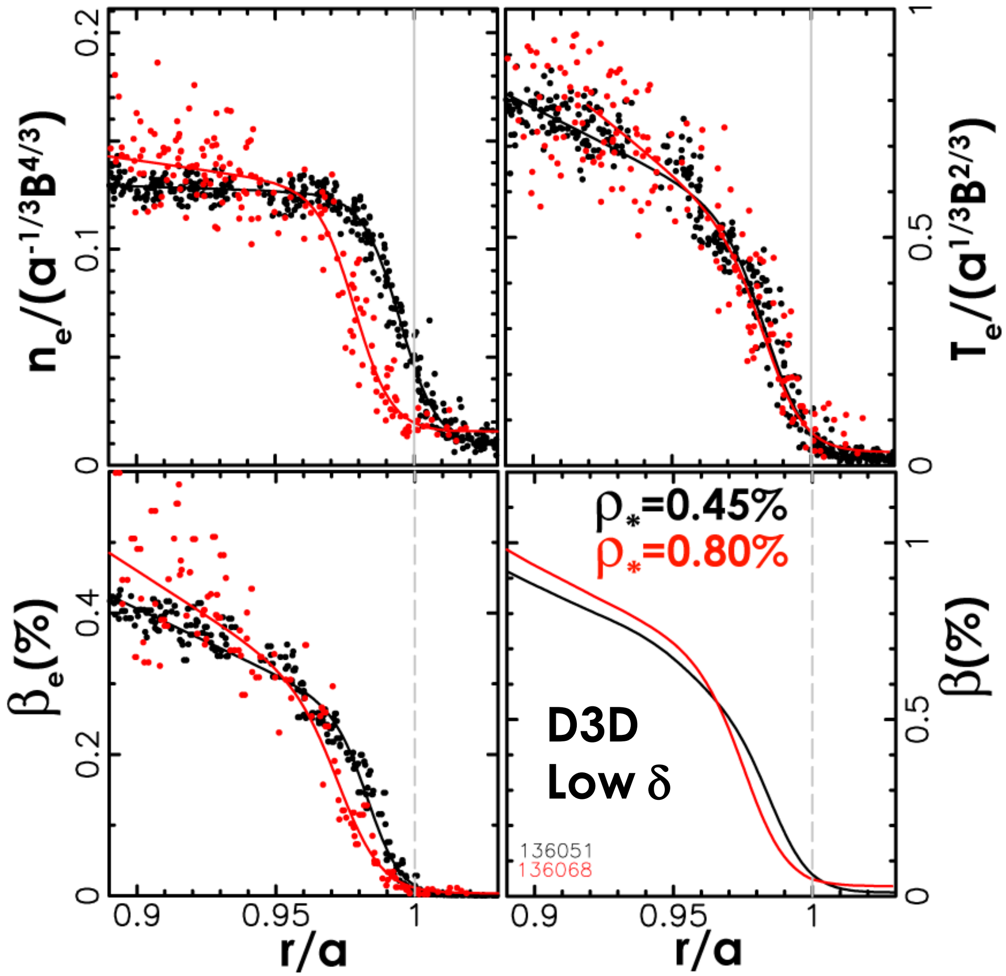
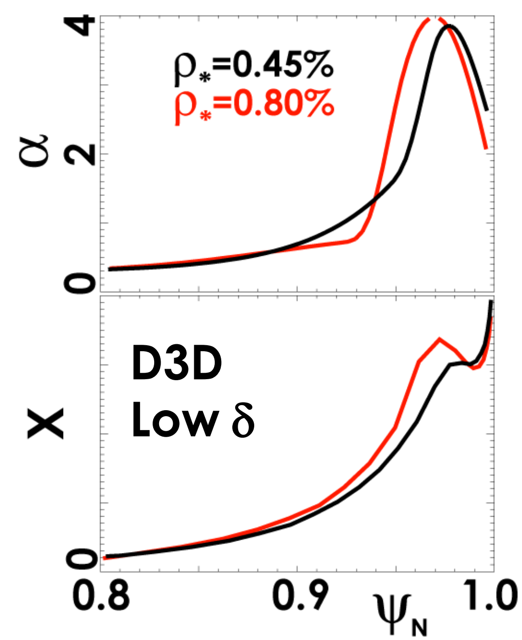
High Edge p′ Region and PB Eigenmode are Wider Due to Density Profile Shift at High ρ_* but Change is Modest Compared to ELM Size Increase



- The n_e profile shift, possibly related to λ_n effects, results in narrowing of width of the high p′ region at small ρ_* (high n_e)
- A modest increase in PB eigenmode width is associated with expansion of high p′ region



Summary Conclusion

- **$w_{Te} \propto a$ at matched dimensionless pedestal parameters $\Rightarrow$ plasma physics and not neutrals set w_{Te}**
- **Outward shift of n_e profile at high n_e (small ρ_*) consistent with particle source affect on n_e profile**
  - Fitting JET results into this picture requires main chamber dominated particle source in JET
- **w_{Te} and w_{ne} weakly decreasing through a factor of 4 variation in ρ_* : $w_{Te}(\psi_N) \propto \rho_*^{-0.17}$, $w_{ne}(\psi_N) \propto \rho_*^{-0.10}$**
  - Combining a β^{PED} scan with the ρ_* scan recovers the EPED1 $(\beta_P^{PED})^{0.5}$ scaling but suggests a residual ρ_* dependence: $w_{Te} \propto (\beta_P^{PED})^{0.5} \rho_*^{-0.25}$
- **ELM energy loss increases strongly with ρ_* on DIII-D but is weakly decreasing with ρ_* on JET**
  - Large losses at high ρ_* on DIII-D > 2× Loarte ν_* scaling
  - ELM size and ELM depth correlated with PB eigenmode width but change in PB width is small compared to ELM size change