Correlation of H–mode Barrier Width and Neutral Penetration Length

by
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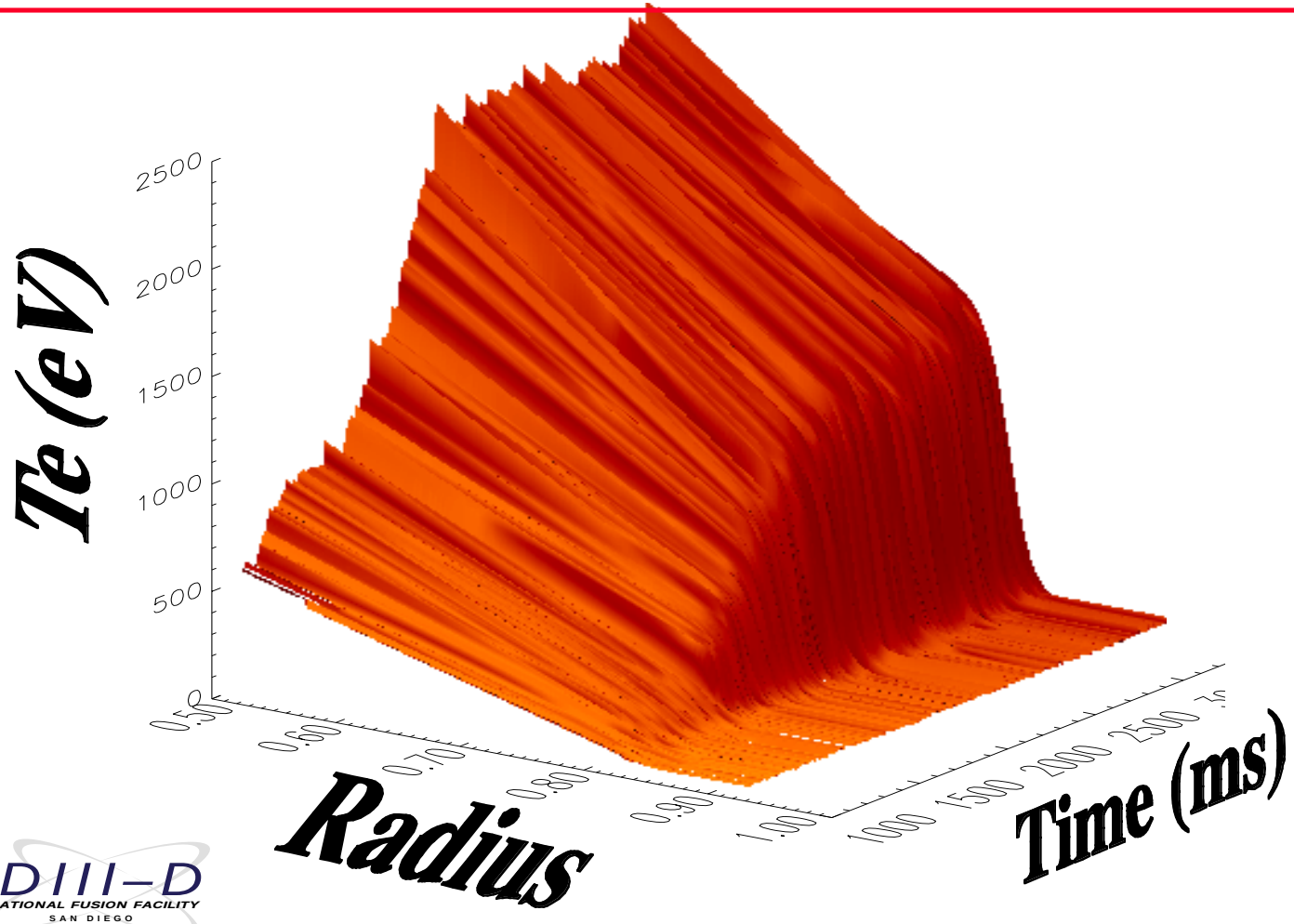
Future Machines Need Adequate Pedestal Height

- Core confinement increases as pedestal height increases
- MHD limits T_{ped} for a given pedestal width (Snyder - Thurs AM)
- We need to understand scaling of pedestal *width*



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This Talk Examines a Self-consistent Theory for H-mode Barrier Structure

Hinton & Staebler time-dependent numerical transport calculations have produced "H-mode" profiles - ***Phys. Fluids B*** **5** ***1281 (1993)***

Ω_{ExB} reduces transport

$$\Omega_{ExB} \sim \frac{\partial n_i}{\partial r}\frac{\partial p_i}{\partial r}$$

$$\lambda_{barrier} \approx \lambda_\Gamma f(Q)$$

Transport barrier width determined mainly by particle source and increases weakly with heat flux.

This talk examines two questions posed by Hinton-Staebler model

- **Is steep gradient region of density profile equal to fuelling depth?**
- **Does steep gradient region of density profile set minimum size of transport barrier width?**

Lebedev, Diamond, Carreras have analytic model with similar physics for barrier formation - ***Phys. Plasmas*** 4 ***1087 (1997)***

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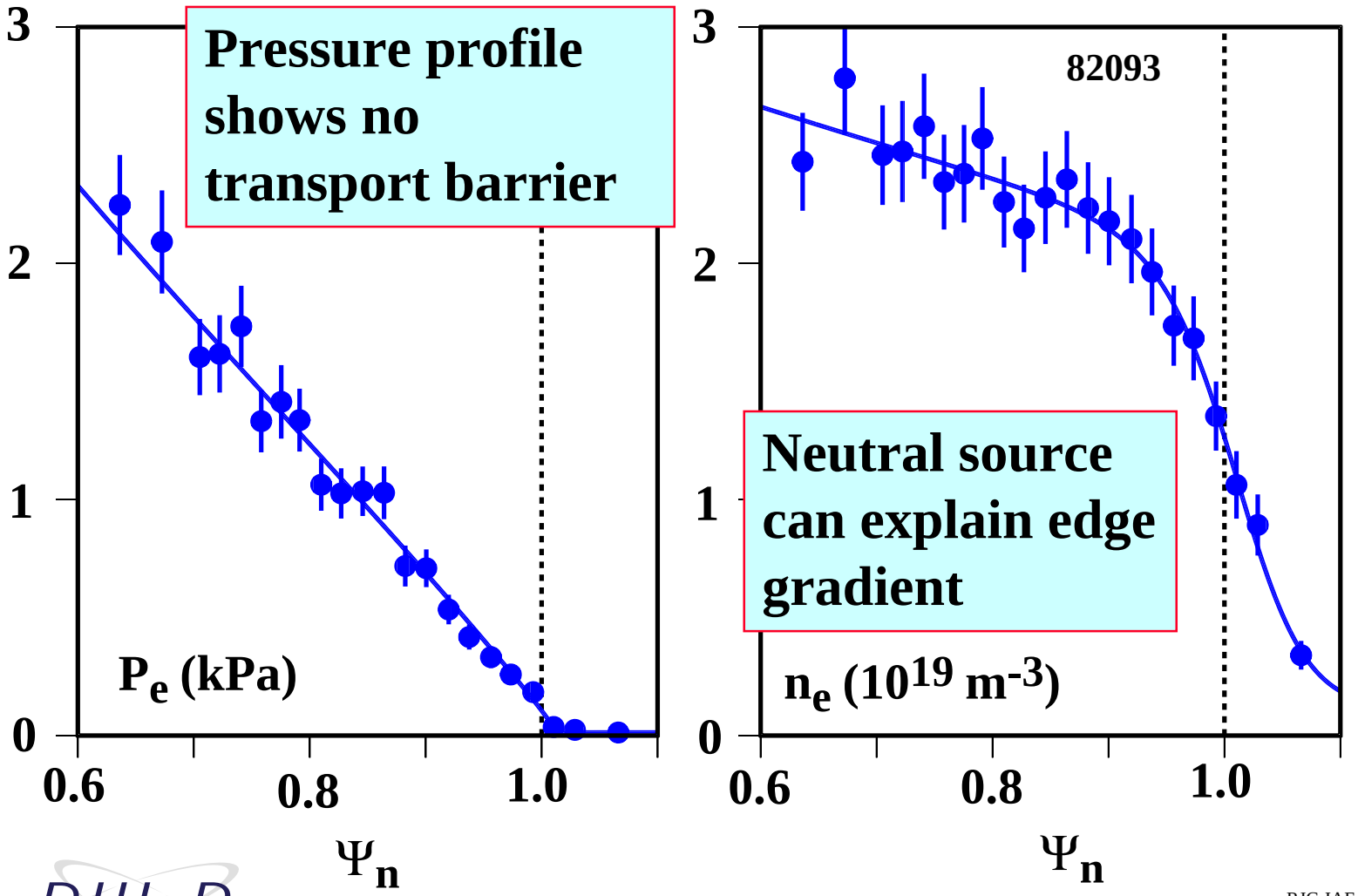
L-mode Edge Density Gradient Provides Motivation to Examine Neutral Fuelling



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Analytic Model Developed to Compute Edge Electron Density Profile (Mahdavi)

Wagner, Lackner, Engelhardt solved coupled equations for density and neutral atoms[1,2]

$$\nabla \bullet \left(D \frac{\partial n_e}{\partial x} \right) = n_n n_e S_i$$

$$V_n \frac{\partial n_n}{\partial x} = -n_n n_e S_i$$

- **Mahdavi extended model and applied to H-mode density[3]**
  - **Poloidally localized fuelling, Frank-Condon and CX neutrals, step in D across LCFS, . . .**
- **Model valid for edge T_i ~ 40-500 eV**
- **Assume $\lambda_{ion} \leq \lambda_{barrier}$**
- **Case of $\lambda_{ion} \geq \lambda_{barrier}$ modifies details but not basic conclusions[4]**
- **Benchmarked against UEDGE 2D edge modeling code[5]**

[1] F. Wagner and K. Lackner, *Physics of Plasma-Wall Interactions in Controlled Fusion*, Series B, Physics Vol. 131, 931 (1986).
[2] W. Engelhardt, W. Fenenberg, J. Nucl. Mater. 76-77 (1978) 518.
[3] M.A. Mahdavi et al., Nucl. Fusion 42 (2002) 52
[4] P. Stangeby, to be published
[5] N. Wolf, Proceedings of 2002 PSI

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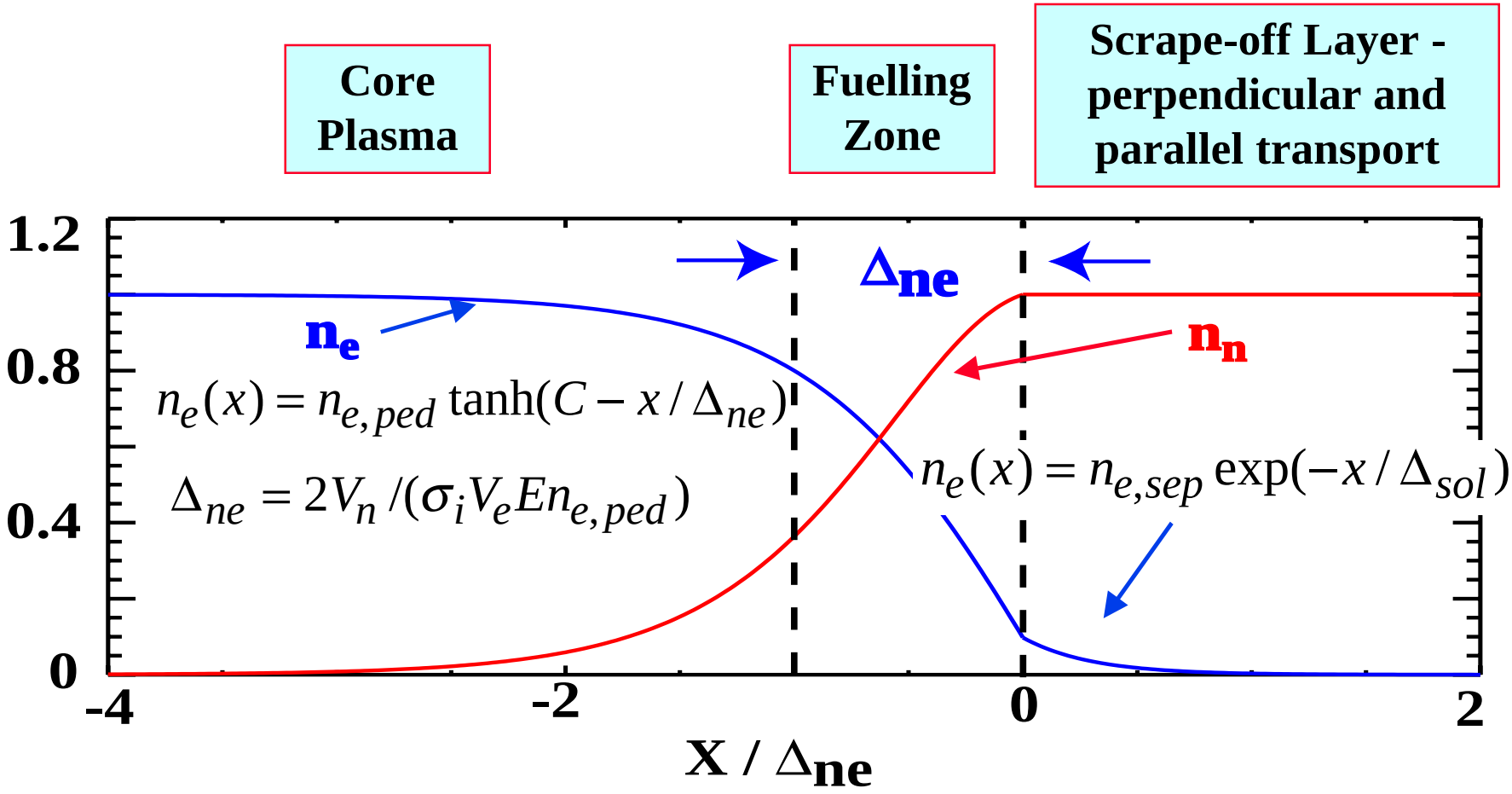
Model Predicts that Electron and Neutral Profiles Have Same Scale Lengths Inside Separatrix - Δ_{ne}



Δ_{ne} is approximately λ_{ion}

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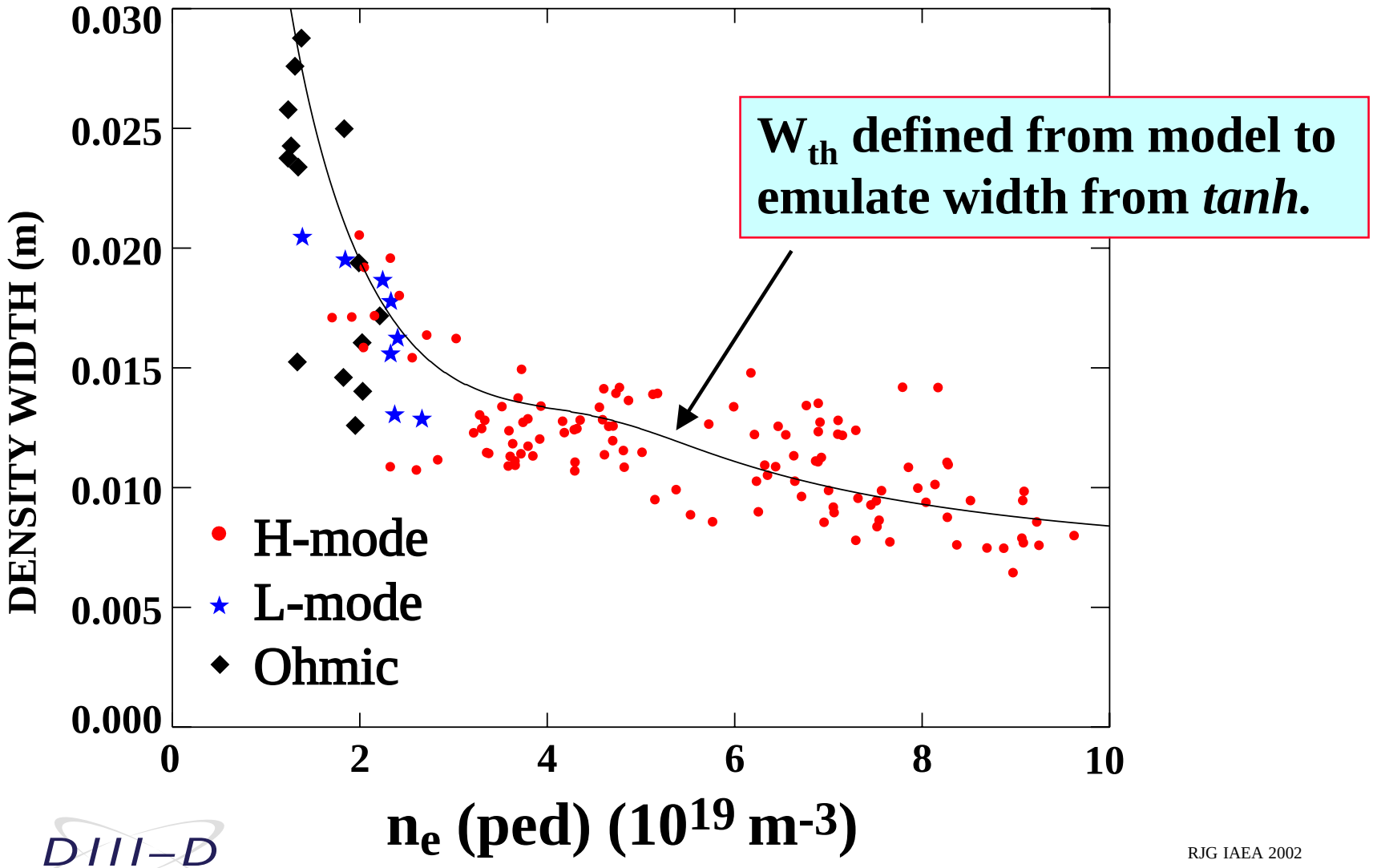
Analytic Model Predicts Observed Decrease of Density Width vs Pedestal Density



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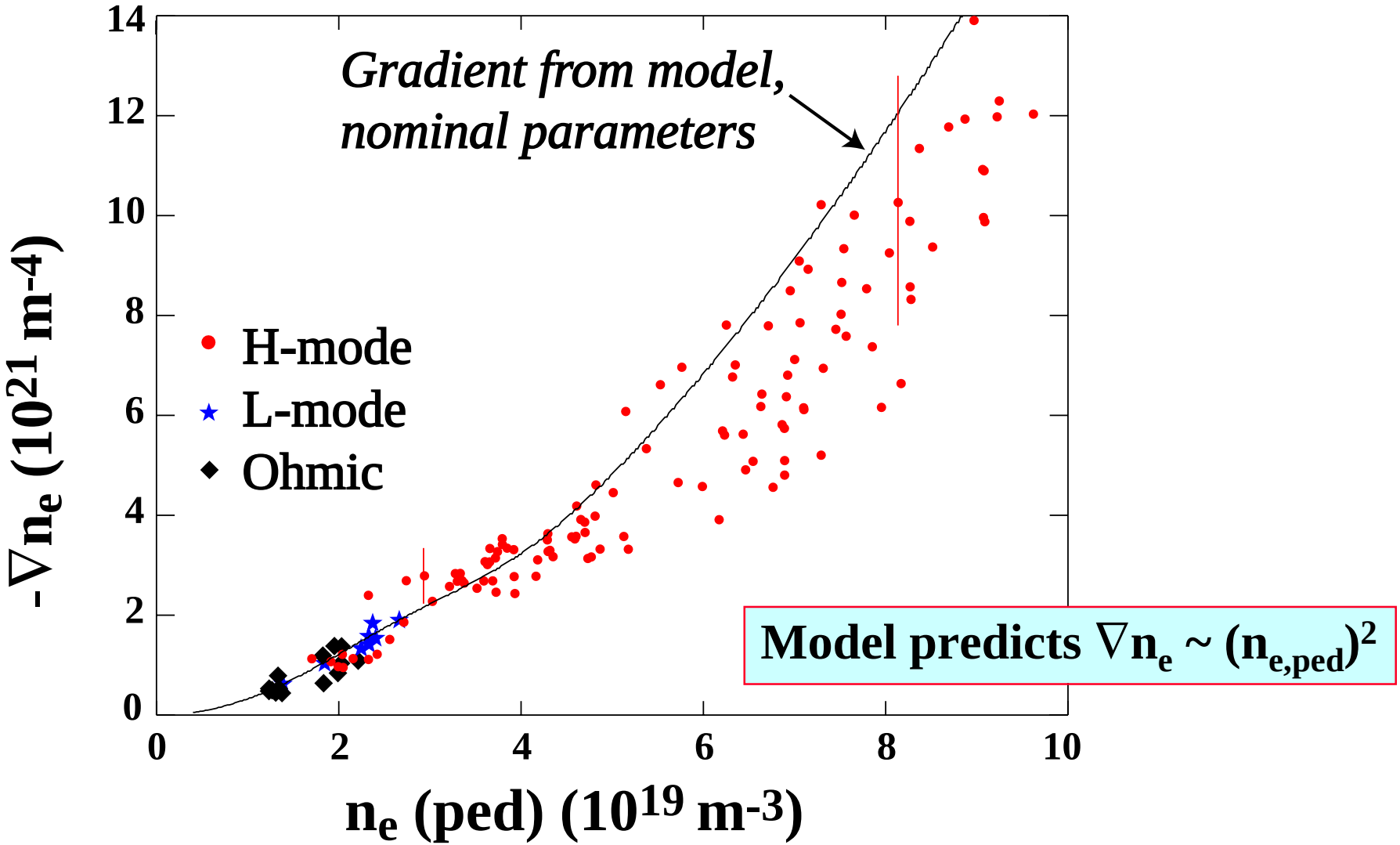
Analytic Model Predicts Observed n_e Gradients



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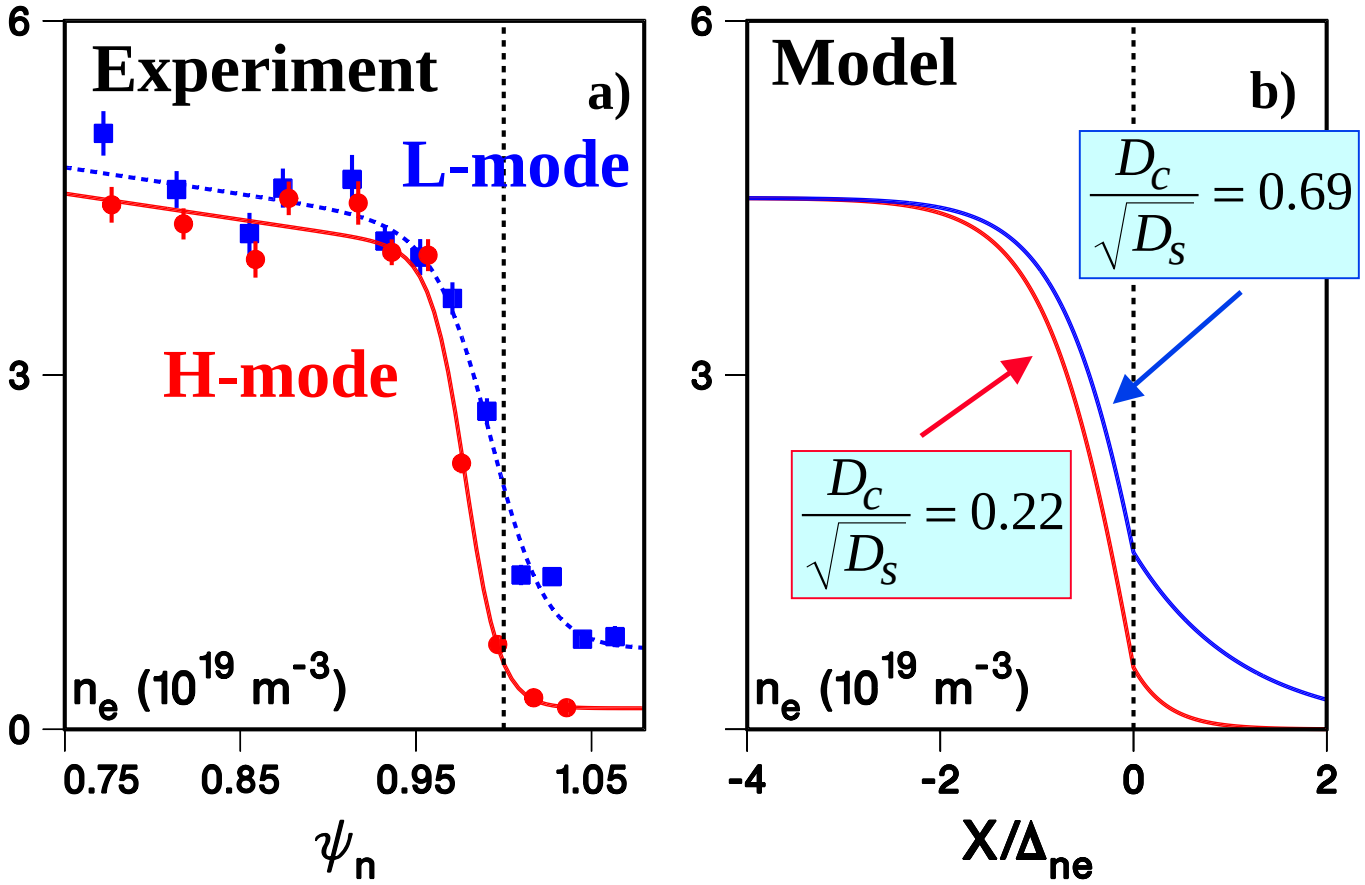
Model Predicts: For Same $n_{e,ped}$, L-mode and H-mode n_e Profiles Have Similar Shape

Widths from separatrix to pedestal are similar.
Different $n_{e,sep}$ can be explained by different transport coefficients.

$$\Delta_{ne} \sim 1/n_{e,ped}$$

$$\frac{n_{e,sep}}{n_{e,ped}} \sim \frac{D_c}{\sqrt{D_s}}$$



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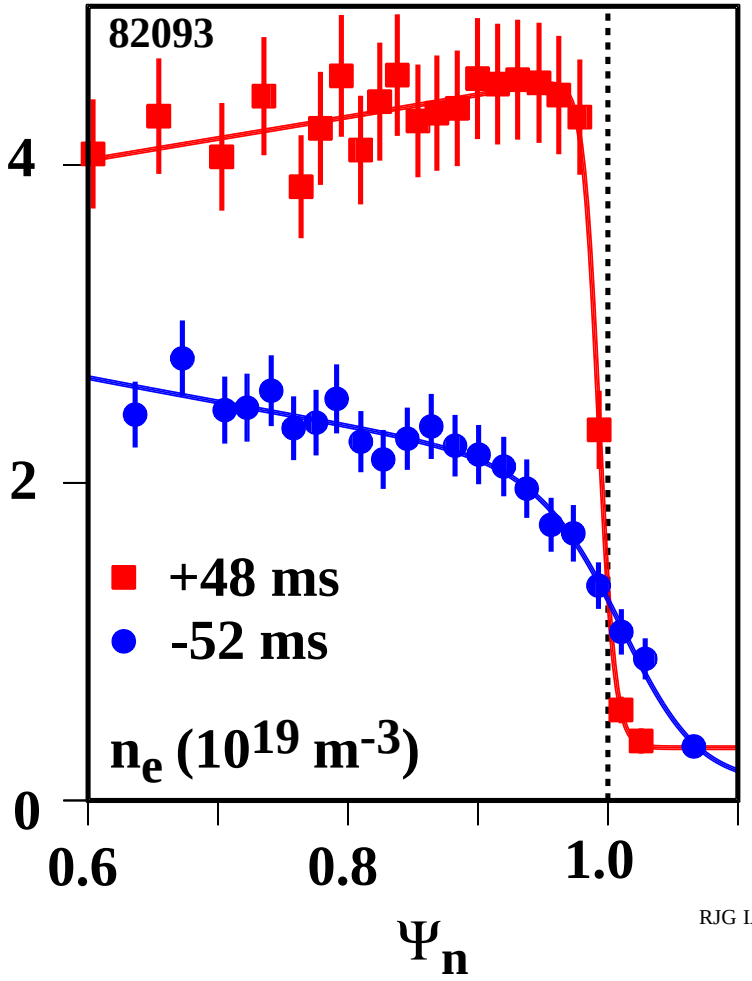
Changes in Density Profile from L to H Are Consistent with Plasma Physics Plus Atomic Physics

Decrease in width and increase in gradient of density at L-H transition is consistent with reduced diffusion coefficient with ~ constant fuelling.

$$\Delta_{ne} \sim 1/n_{e,ped}$$

$$\nabla n_e \sim (n_{e,ped})^2$$



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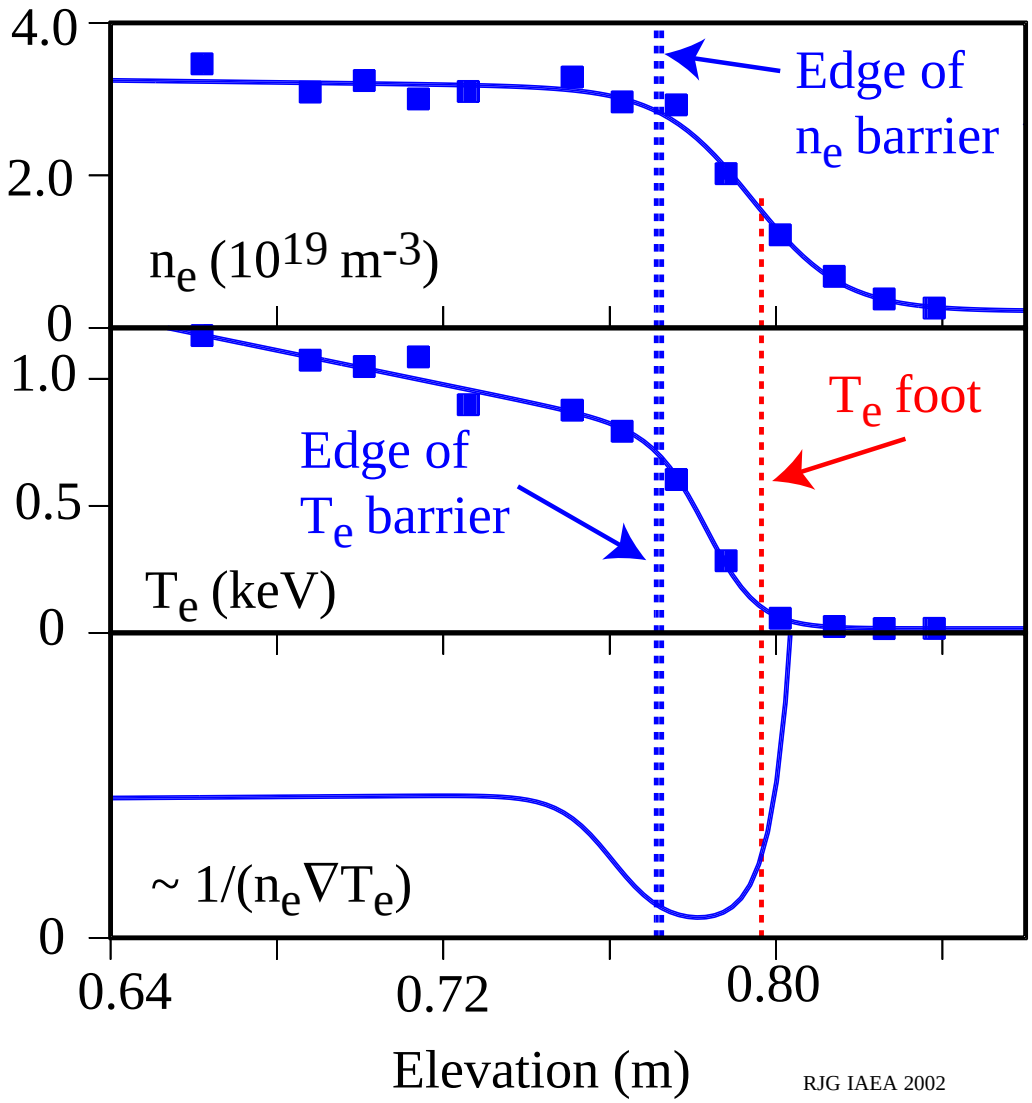
Does steep gradient region of density profile set minimum size of transport barrier?

- **Hinton & Staebler : Transport barrier width determined mainly by particle source and increases weakly with heat flux**
- **To test, use ΔT_e from *tanh* as measure of $\lambda_{barrier}$**
- **Measure Δn_e from T_e foot to inner edge of n_e barrier**



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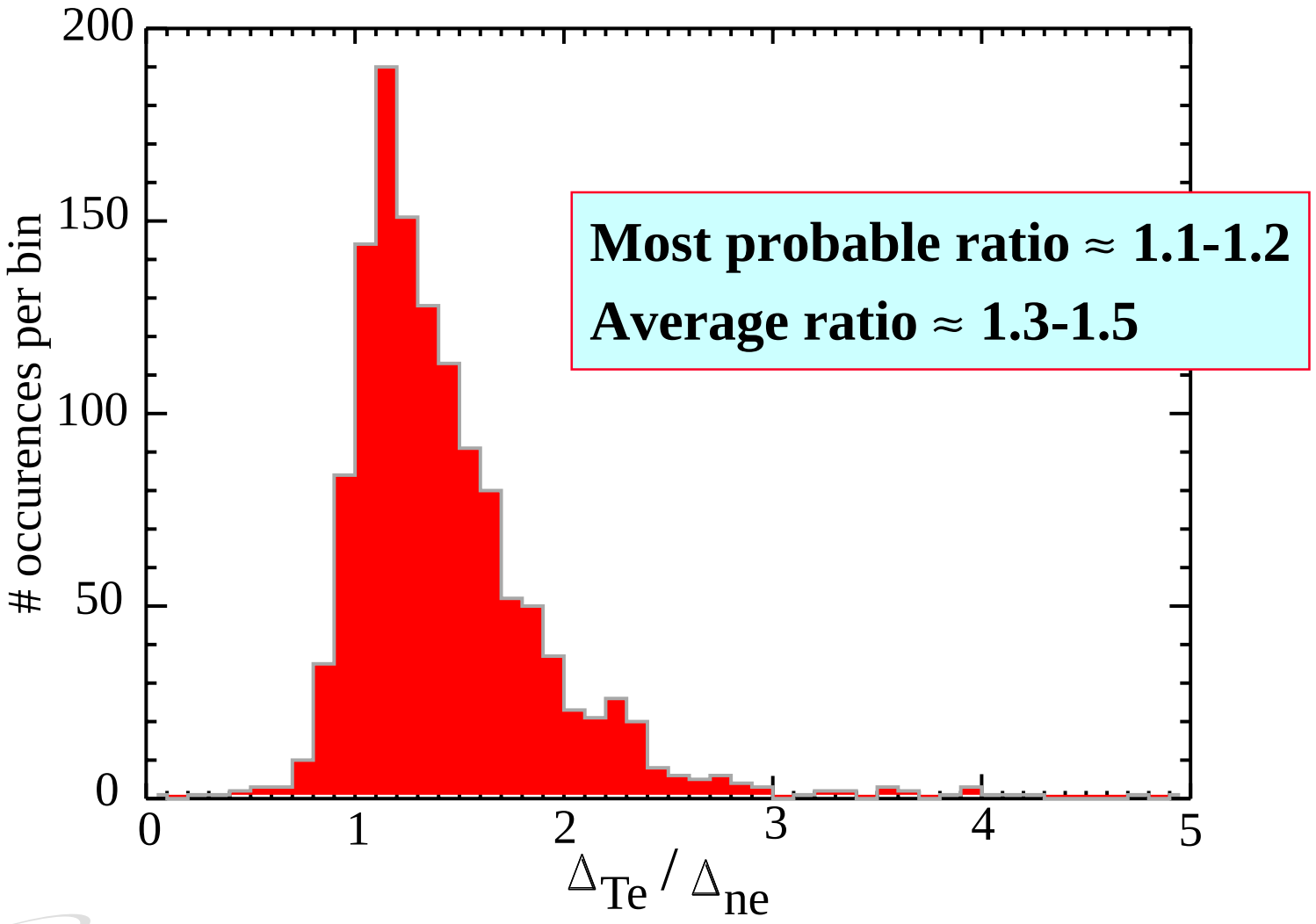
Width of Density Step Provides Lower Limit for Width of Transport Barrier



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Summary and Conclusions

- **Is width of steep gradient region in H-mode density profile approximately equal to fuelling depth?**
  - **Yes, DIII-D evidence strongly supports this picture**
  - **Widths and gradients of n_e profile scale and have approximate magnitudes expected from a model, including transport and fuelling**
  - **Model provides unified view of L-mode and H-mode n_e profiles**
- **Does density step width set minimum size of transport barrier?**
  - **Yes, clear evidence in support of this idea**
  - **T_e barrier is always as wide as or wider than n_e step**
- **These data and analysis support hypothesis that minimum H-mode barrier width is set by fuelling**
- **Scaling of transport barrier remains unknown**
  - **MHD, poloidal gyroradius, magnetic shear, etc. might be important (Osborne -Wed pm)**

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Possible Implications for Next Step Machines

- **This picture for minimum transport width has no intrinsic size scaling and scales unfavorably as density is increased**
- **Some issues can modify the picture:**
  - **Transport barrier can be wider than density step**
    - Scaling is not known
  - **At higher temperature, increased neutral velocity and cross section effects (e.g., reduced ionization rate) will lead to deeper neutral penetration and wider density step**
    - Possible evidence from VH-mode, which has wider density step than expected from analytic model but also higher temperature than valid in model
- **An idea for pedestal control**
  - **Techniques to deposit neutrals deeper into plasma than possible with gas-fuelling may lead to control of pedestal width and gradient**