The Relation Between Upstream Radial Widths of n_e and T_e and Outer Target Power Width for H-mode Discharges in DIII-D

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Heat Flux Scaling

- With better knowledge of the physics controlling target heat width, there is a better chance of knowing how to scale measured widths in present tokamaks to ITER, FNSF, DEMO

Work Plan

- It appears that cross-field transport is the basic controlling process of SOL widths, manifesting itself most directly in upstream widths, with parallel transport and volumetric losses in the SOL/divertor then controlling the relation between upstream and target widths

- Here we focus on identifying the processes controlling the parallel transport of power in the scrape-off layer, SOL

- We examine the relation between upstream widths, $\lambda_{T_e}^{up}$, $\lambda_{n_e}^{up}$, measured by a reciprocating probe and Thomson scattering – and target power widths $\lambda_{q_{target}}^{measured}$ measured by ir thermography, for low and medium density H-mode discharges where the role of volumetric loss in the divertor is not expected to be strong

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TEST HYPOTHESIS: Spitzer Electron Conduction Dominates at Medium Density, Flux-limited Elec. Heat Convection at Low

- It has long been assumed that parallel power transport in the SOL is largely due to classical, collisional Spitzer electron heat conduction $q_{||} = \kappa_{0e} T_e^{5/2} \partial T_e / \partial s_{||} \propto T_e^{7/2} / L_{||}$ and thus one expects to observe $\lambda_{q_{target}}^{measured} \approx \lambda_{q_{target}}^{Spitzer} \equiv \boxed{\lambda_{q_{||}}^{Spitzer} = (2/7)\lambda_{T_e}^{up}}$.

- Here we postulate that $\lambda_{q_{target}}^{Spitzer}$ should occur at medium density, where the SOL is collisional but volumetric power loss in the SOL is not yet strong.

- For lower density, collisionless, SOL conditions we postulate that flux-limited electron heat convection dominates $q_{||} \approx n_e k T_e \sqrt{kT_e / m_e} \propto n_e T_e^{3/2}$ and thus one expects to observe $\lambda_{q_{target}}^{measured} \approx \lambda_{q_{target}}^{flux-lim} \equiv \boxed{\lambda_{q_{||}}^{flux-lim} = 1/\left[1.5/\lambda_{T_e}^{up} + 1/\lambda_{n_e}^{up}\right]}$.

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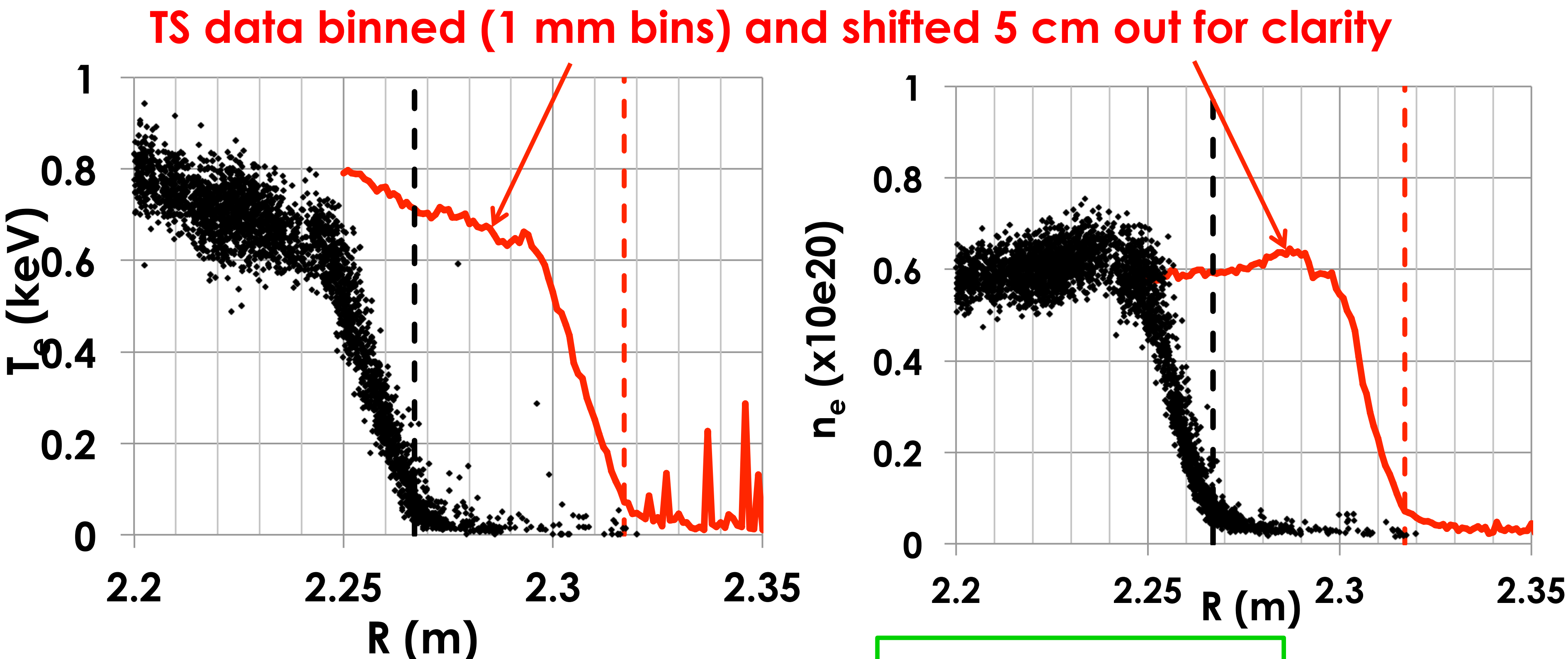
The Thomson System Provides Excellent Profiles Across the Separatrix



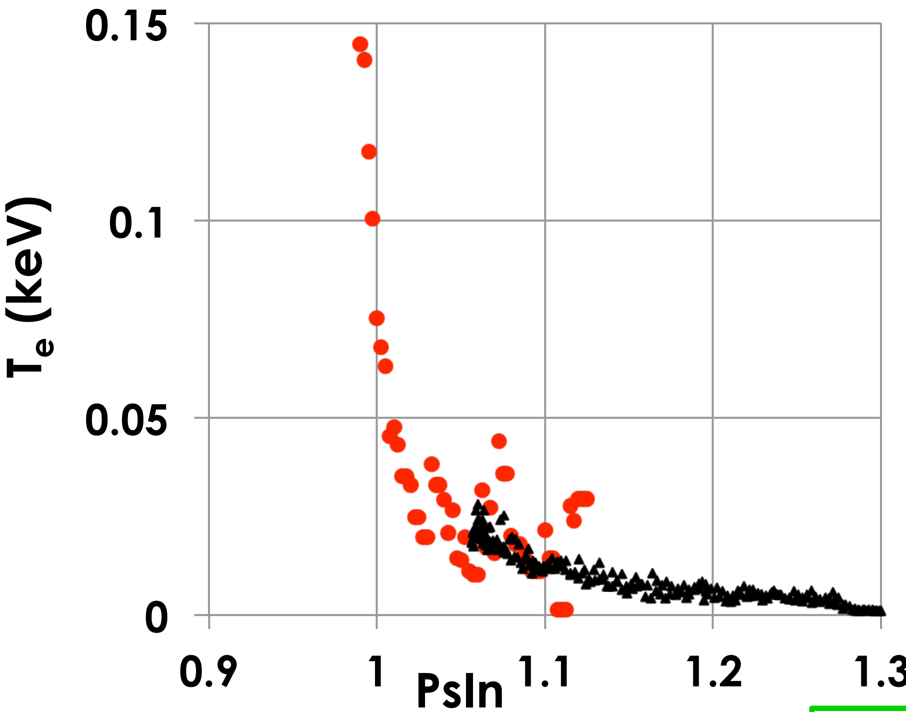
Thomson scattering system located near outside midplane

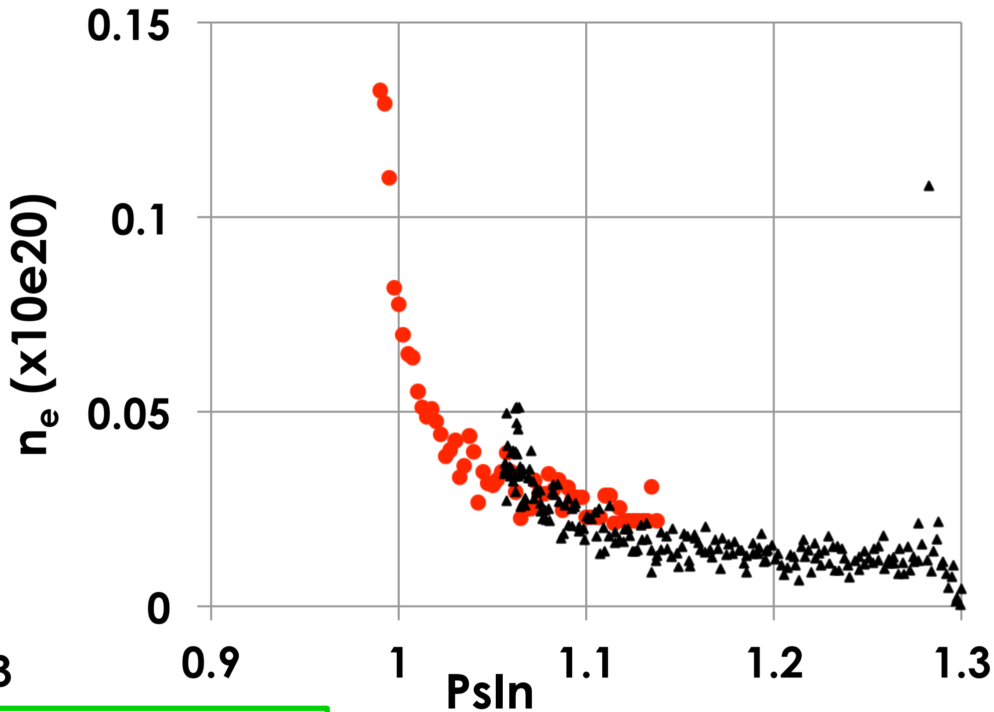
Shot 144977
P_{NBI} = 2.5 MW
ELMs removed

B Bray
A Leonard

The Reciprocating Probe (RCP) and Thomson Data Agree Very Well Where they Overlap

Thomson (red) Probe (black)





Shot 144977
P_{NBI} = 2.5 MW
ELMs removed

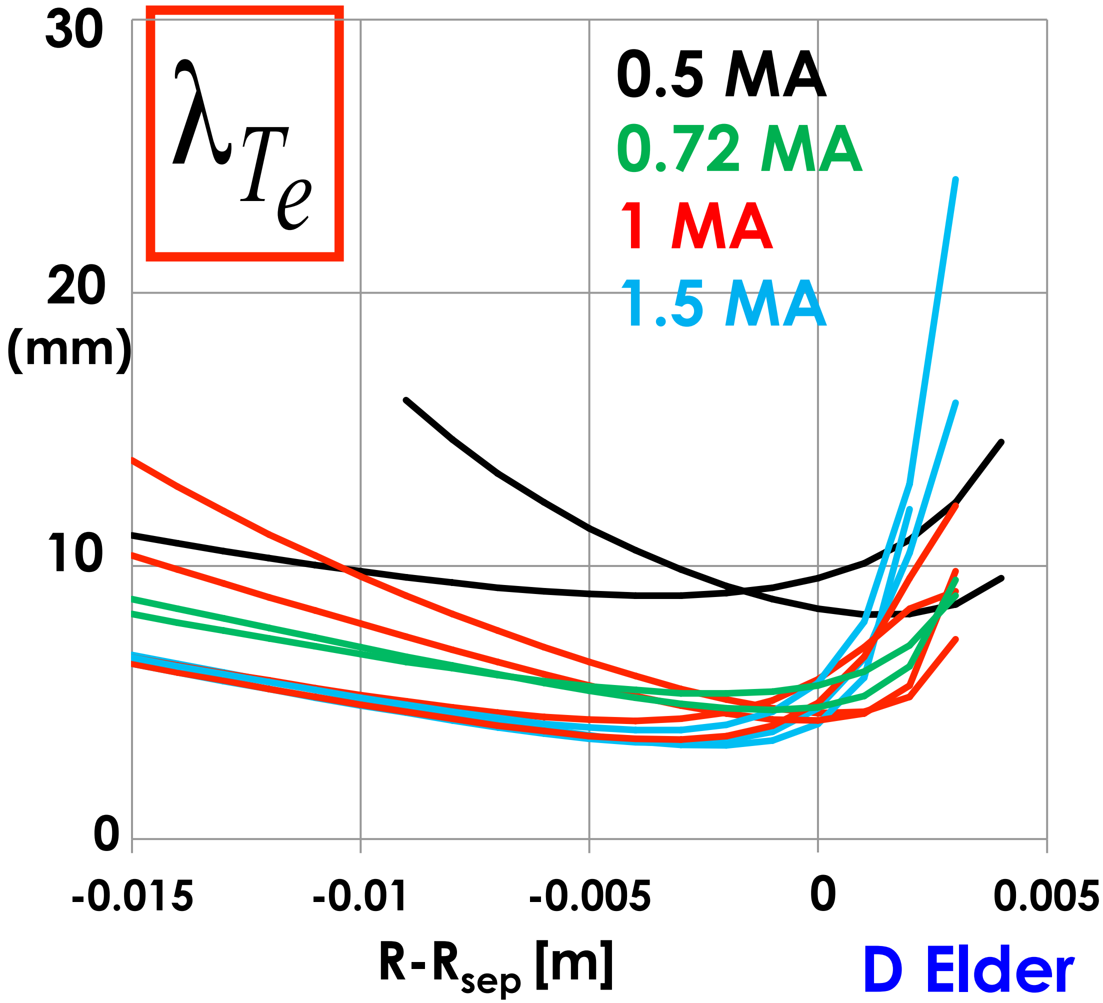
RCP: J Boedo

The Definition of "Width" Used Here

- **In this work all Thomson widths are the gradient lengths from 3rd order polynomial fits to the measured profiles over a span of ~10 mm centered on the separatrix, then mapped to the outside midplane**

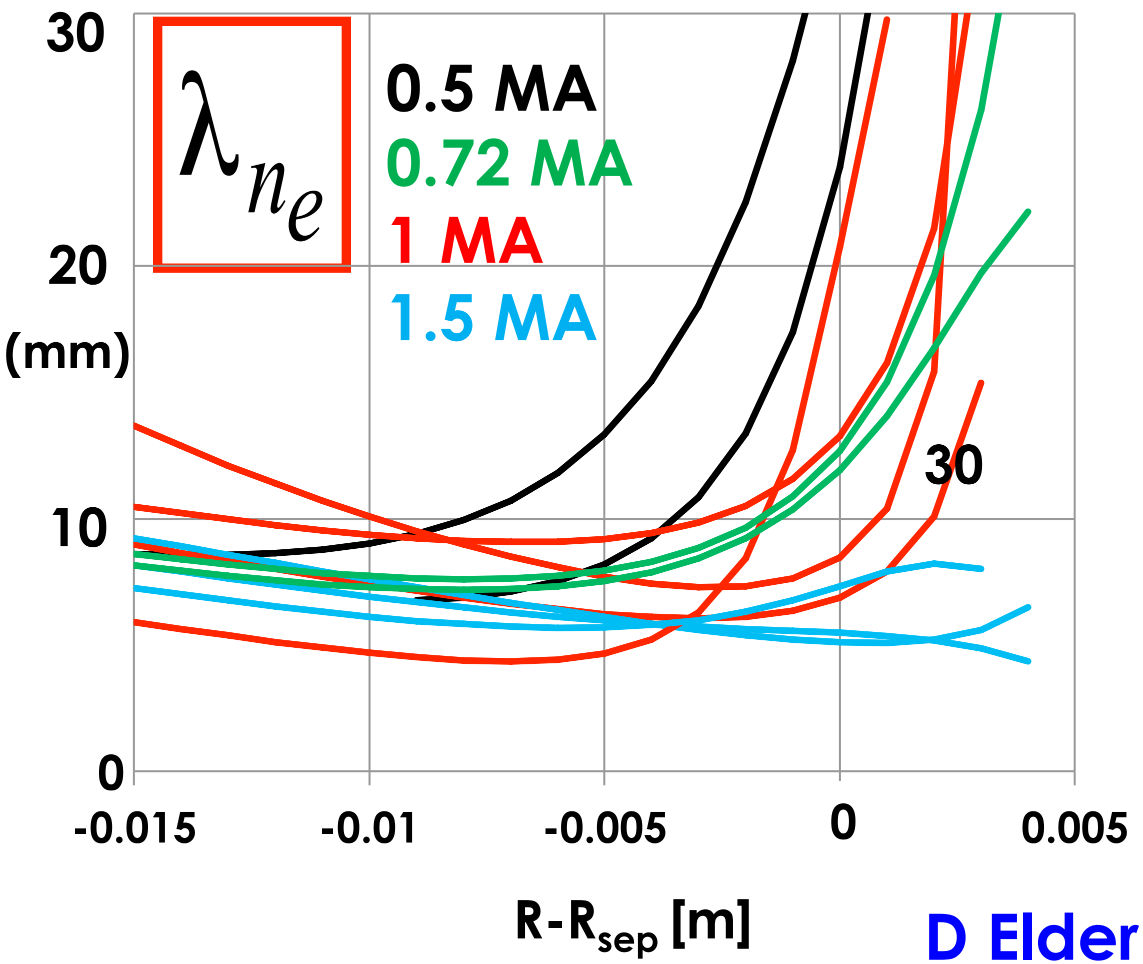
- **Outer target power widths are exponential fits to the power profiles on the common flux side, then mapped to the outside midplane**

T_e Radial Decay Lengths from Time-averaged Thomson Data Over the Steady Part of Each Shot



- The values of $\lambda_{T_e}^{up}$ contribute to both $\lambda_{q_{||}}^{Spitzer} \equiv (2/7)\lambda_{T_e}^{up}$ and $\lambda_{q_{||}}^{flux-lim} \equiv 1/\left[1.5/\lambda_{T_e}^{up} + 1/\lambda_{n_e}^{up}\right]$.
- $\lambda_{T_e}^{up}$ at the separatrix doesn't vary much with I_p except at low density.
- In the SOL $\lambda_{T_e}^{up}$ varies rapidly with distance. Therefore uncertainty in the separatrix location is the most important source of error.

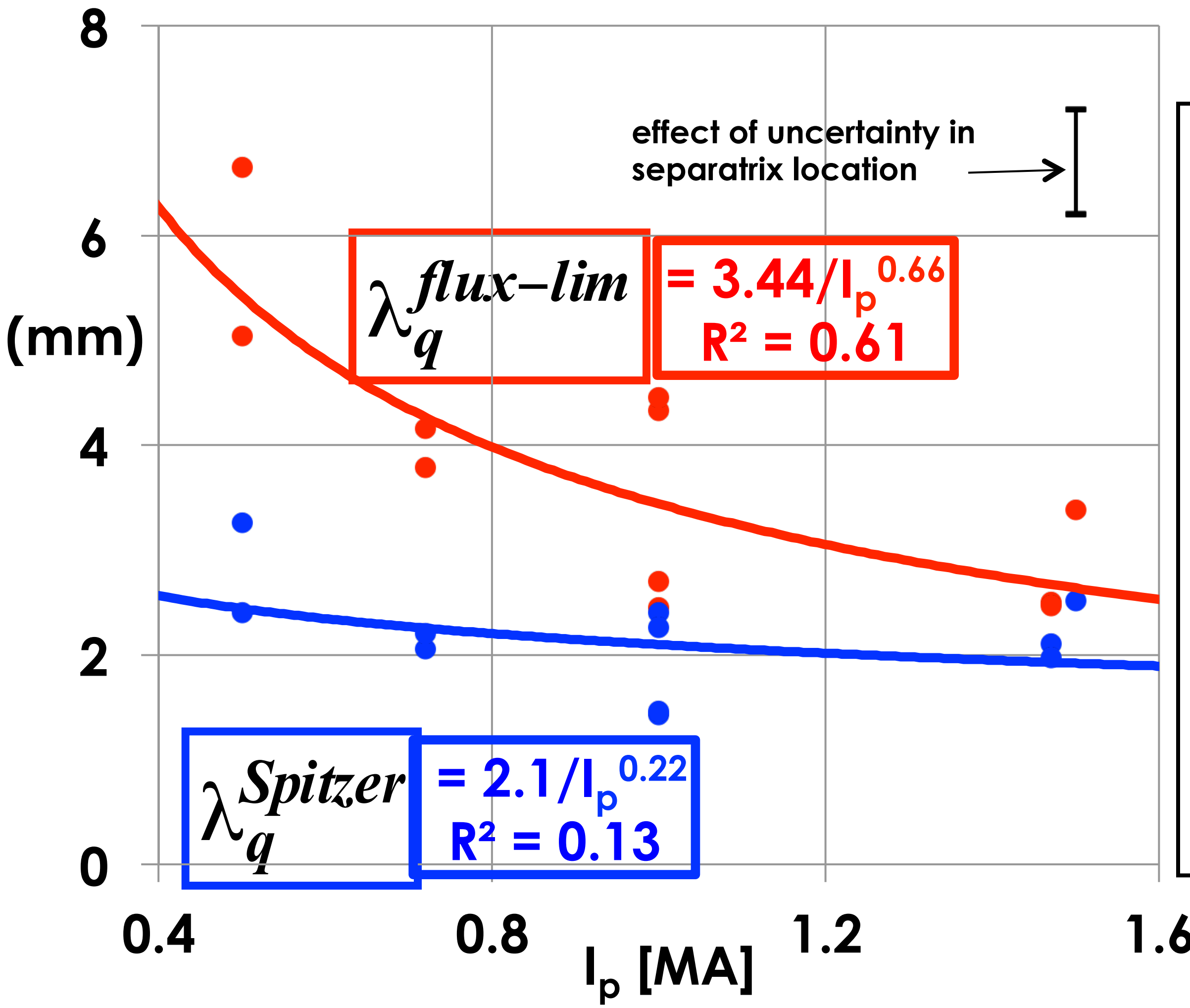
n_e Radial Decay Lengths from Time-averaged Thomson Data Over the Steady Part of Each Shot



D Elder

- The values of $\lambda_{n_e}^{up}$ play no role in $\lambda_{q||}^{Spitzer} \equiv (2/7)\lambda_{T_e}^{up}$ but effect $\lambda_{q||}^{flux-lim} \equiv 1/\left[1.5/\lambda_{T_e}^{up} + 1/\lambda_{n_e}^{up}\right]$.
- $\lambda_{n_e}^{up}$ at the separatrix varies appreciably with I_p.
- In the SOL $\lambda_{n_e}^{up}$ varies rapidly with distance. The uncertainty in the separatrix location, however is less important than for $\lambda_{T_e}^{up}$ when $\lambda_{n_e}^{up}$ becomes >> $\lambda_{T_e}^{up}$.

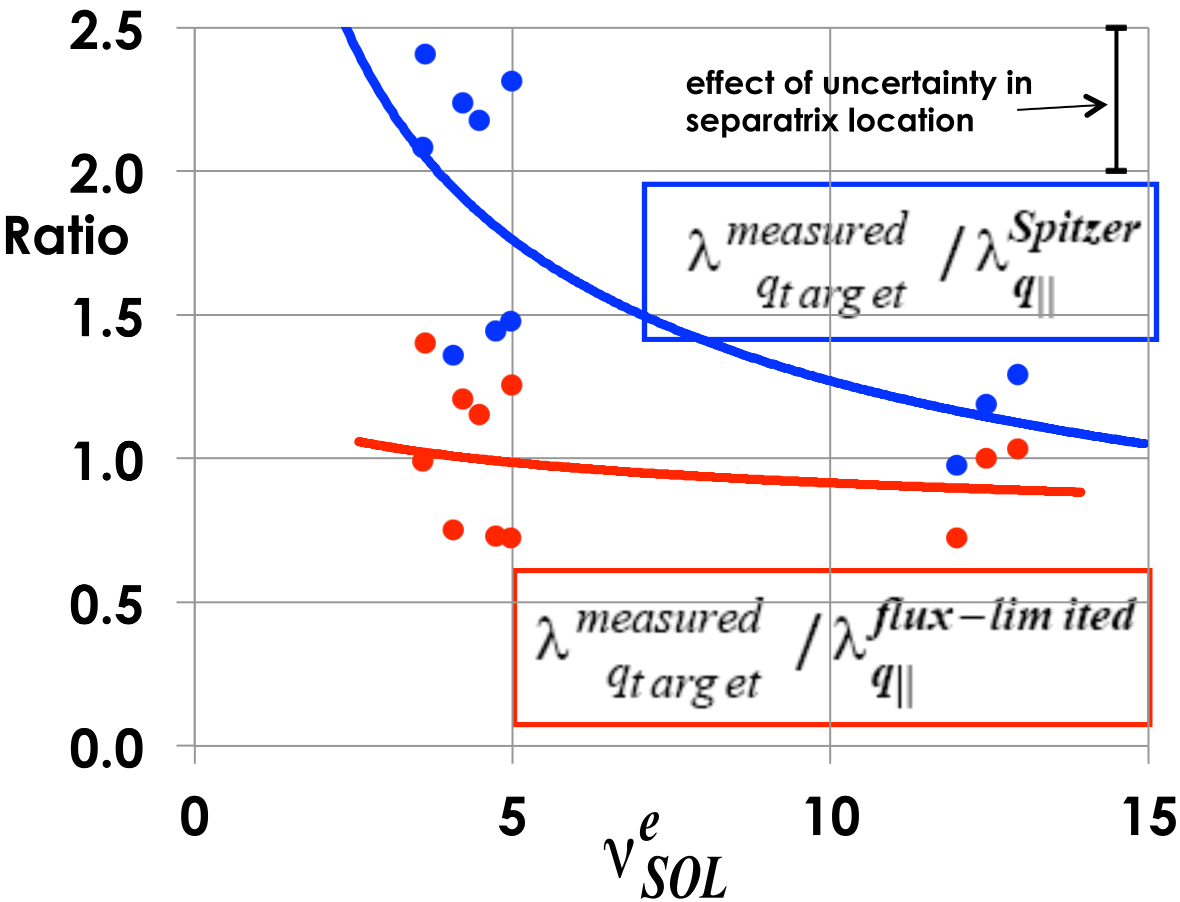
The Spitzer and the Flux-limited Power Widths are Both Correlated with Plasma Current



$\lambda_q^{flux-lim} = 3.44 / I_p^{0.66}$ is very similar to the scaling reported by M Makowski, this meeting, for $\lambda_{q\,target}^{measured}$ for H-mode DIII-D shots:

$$\lambda_{q\,target}^{measured} = 3.26 / I_p^{0.7}$$

Ratios of Measured Target Power Width to Spitzer and Flux-limited Power Widths are Consistent with TEST HYPOTHESIS, Although Scatter/ Error is Significant



- Error is mainly due to uncertainty in separatrix location
- Lines are best fits to a power-law relation
- Convergence of Spitzer and flux-limited is theoretically predicted to occur at ν_{SOL}^{e} = 10–20 [Stangeby, Canik & Whyte, Nuclear Fusion 50 125003 (2010)]

ir power widths: C Lasnier. *ELMs removed*

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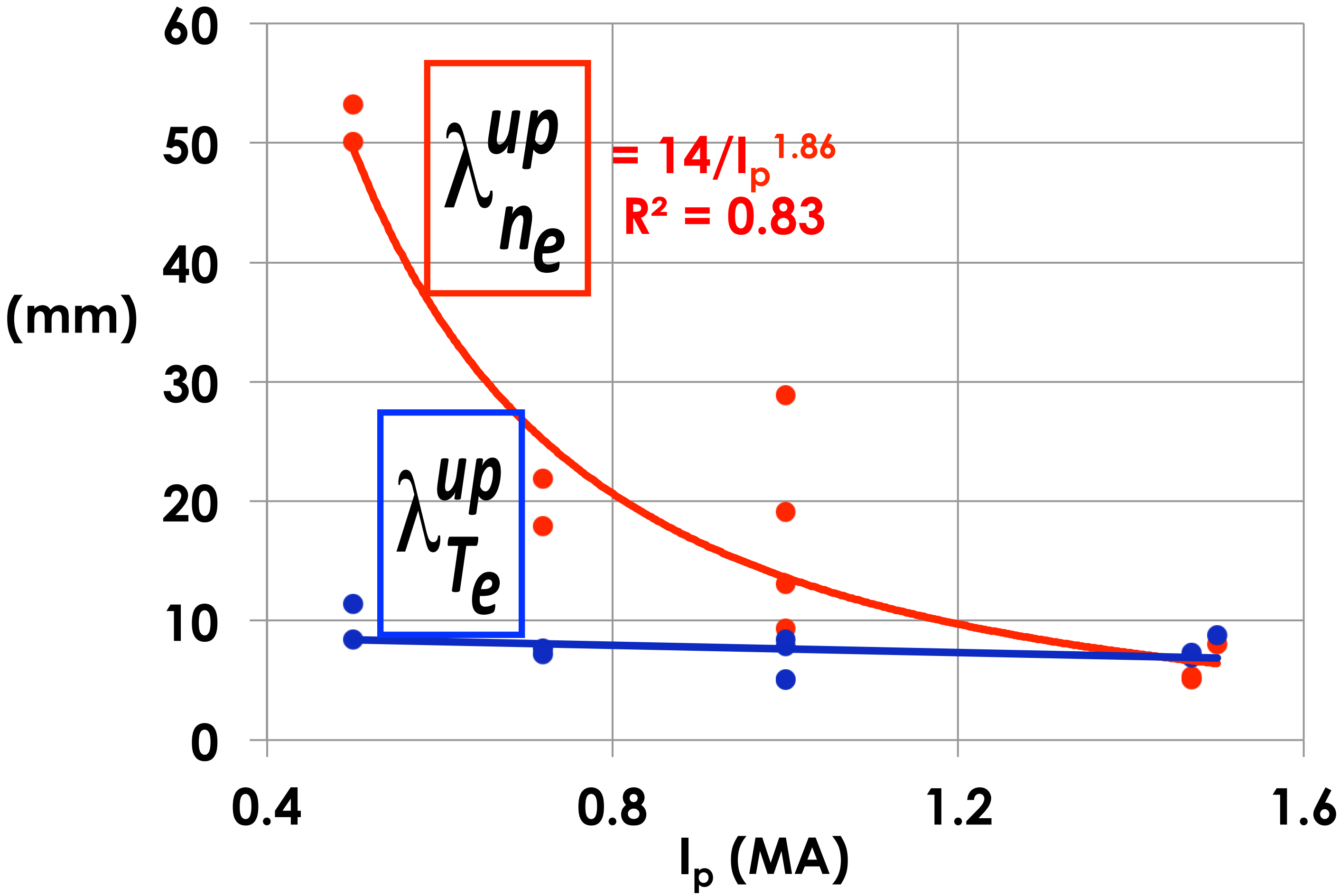
The I_p-dependence of the Target Power Width is due to the I_p-dependence of the Upstream Density Width



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Conclusions

- The hypothesis that Spitzer electron heat conduction controls parallel power transport in the SOL at medium density while flux-limited electron parallel heat convection is controlling at low density, is supported by measurements of upstream n_e and T_e widths and target power widths in a current scan of DIII-D H-mode discharges

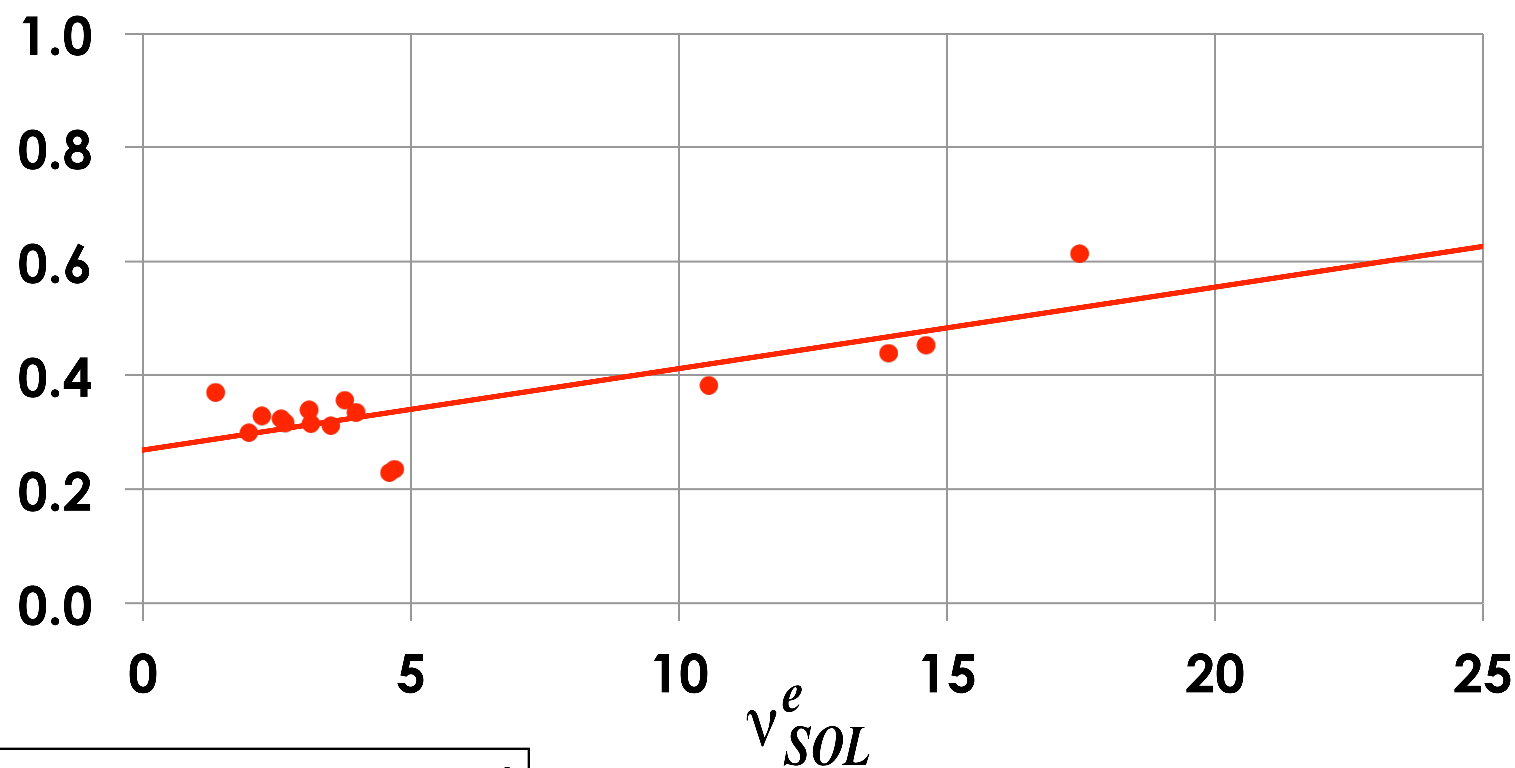
- For the discharges analyzed here the I_p-dependence of the target power width is due to the I_p-dependence of the upstream density width

- Future work will focus on density scans (with I_p constant) and higher density where volumetric power loss in the divertor becomes strong and detachment is approached

Additional Slides

For High Collisionality, nu_SOL_e > ~15, Volumetric Power Loss in the Divertor Becomes Significant, > ~50%. Such Shots are Excluded Here

The ratio $p_{rad}^{divertor} / p_{SOL}$ as a function of SOL electron collisionality ν_{SOL}^{e}



$$\nu_{SOL}^{e} \equiv 10^{-16} n_e^{sep} \pi R_0 q_{95} / \left(T_e^{sep}\right)^2$$

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Discussion

- The target power width $\lambda_{q_{target}}$ is what really matters.
- We want to know: Why $\lambda_{q_{target}}$ is of the size observed?
- The results here support the hypothesis:

not analyzed here → (a) cross-field transport sets $\lambda_{T_e}^{up}$, $\lambda_{n_e}^{up}$, $(\lambda_{T_i}^{up}, \ldots.)$

the focus here → (b) parallel transport sets $\lambda_{q_{||}}^{up}$ $[\lambda_{T_e}^{up}, \lambda_{n_e}^{up}, (\lambda_{T_i}^{up}, \ldots.)]$

not analyzed here → (c) $\lambda_{q_{target}} = \lambda_{q_{||}}^{up}$ + effect of volumetric losses in divertor

- The results here indicate that $\lambda_{q_{||}}^{up}$ $[\lambda_{T_e}^{up}, \ldots]$ is given by electron flux-limited convection for low density and by Spitzer electron conduction for medium density (and by implication for high density also, but not concluded yet).