Investigation of SOL widths with plasma parameters in NSTX H-mode plasmas

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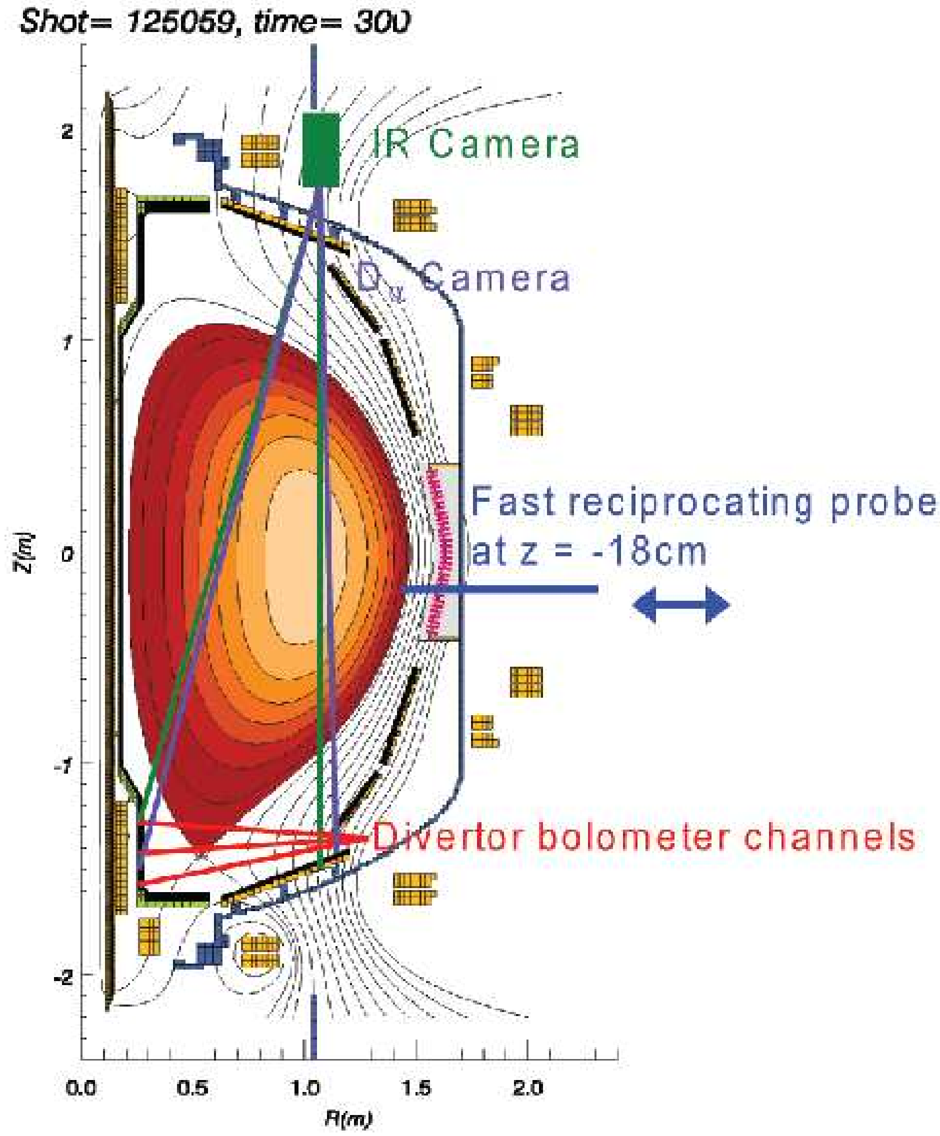
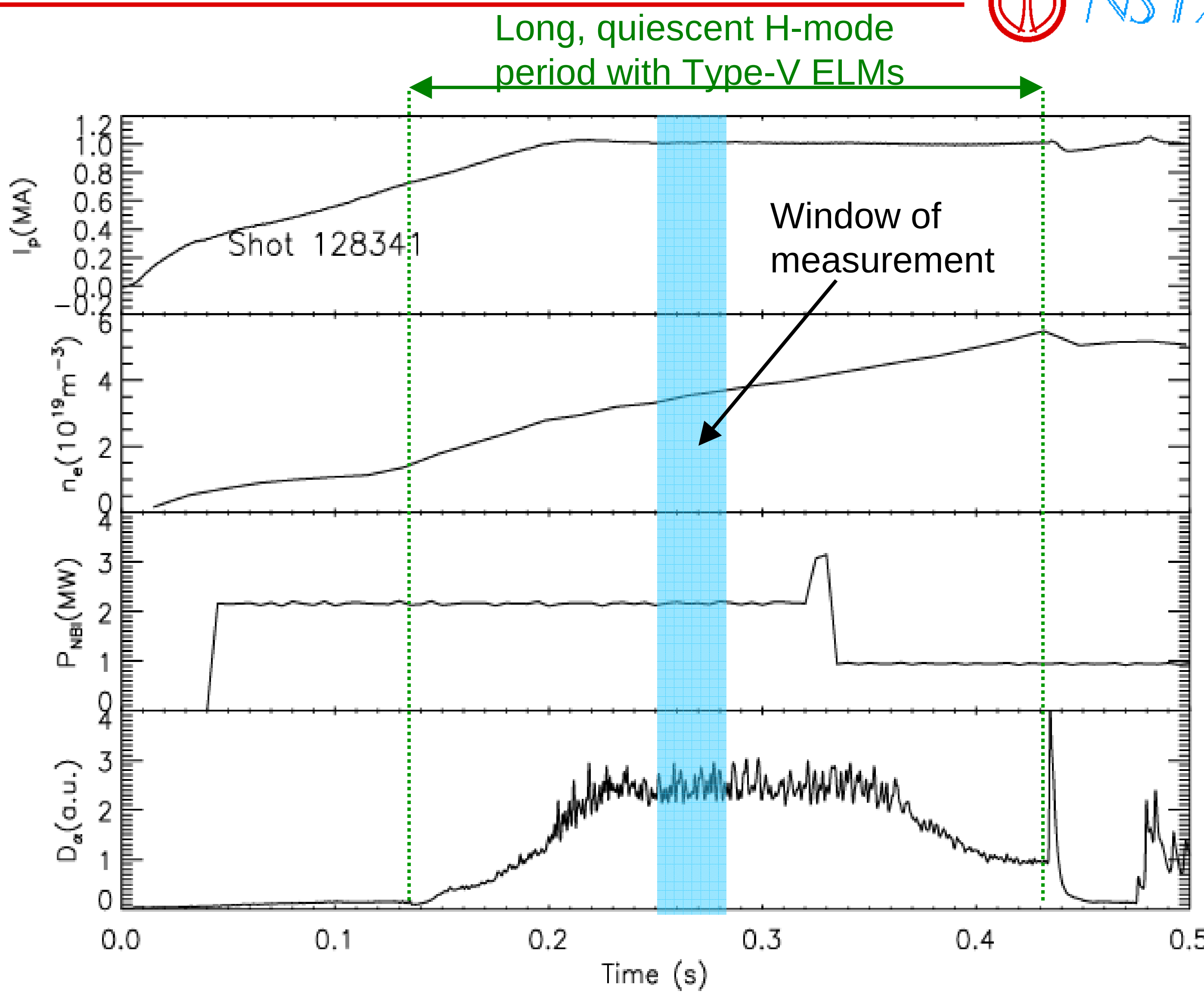
Poloidal cross-section of NSTX



Time trace of discharge parameters



The conduction-limited regime

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As upstream density rises -

- $n_{e,u}$ rises $\Rightarrow$ $T_{e,u}$ falls
- λ_{ee} shortens and $\nu^* >>1$
- Streaming replaced by e^- conduction

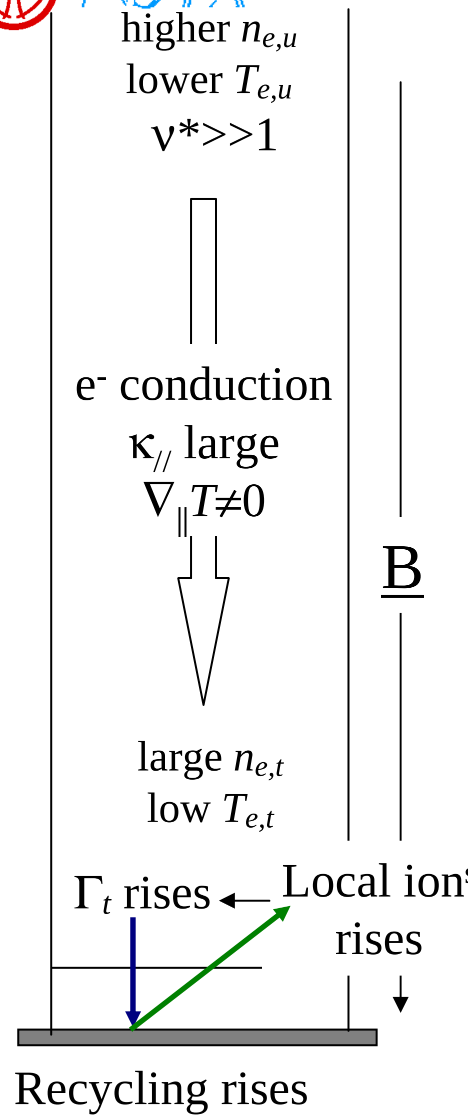
  $\Rightarrow$ heat conductivity $\kappa_{//}$ falls, temperature gradients develop along SOL ($\nabla_{||}T \neq 0$)

  $\Rightarrow$ T_t falls even more than $T_{e,u}$
- Plasma pressure still conserved $\nabla_{||}p \sim 0$

  $\Rightarrow$ n_t rises significantly, ionisation m.f.p. λ_{ion} falls
- Ion flux to target Γ_t rises

  $\Rightarrow$ recycling (release of neutrals by ion impact) increases
- λ_{ion} < scale length of SOL

  $\Rightarrow$ionisation near target increases, further raising Γ_t



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The two-point model (2PM)

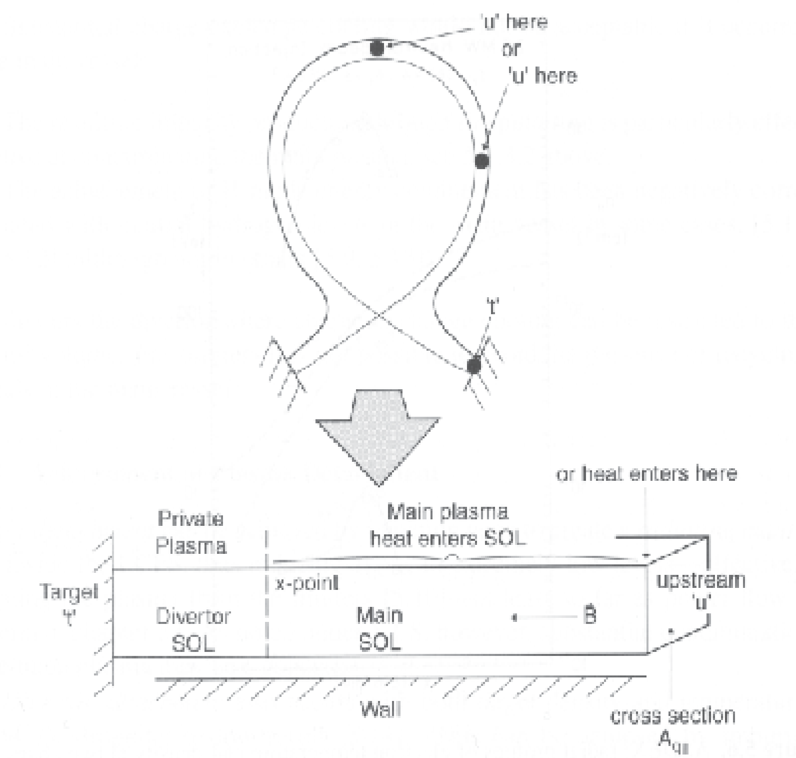


Figure from “The Plasma Boundary of Magnetic Fusion Devices”, P.C.Stangeby, IoP Publishing (2000)

- 0D divertor model
- Simply relating upstream parameters (‘u’, $T_{e,u}$, $n_{e,u}$, etc) to the target ones (‘t’, $T_{e,t}$, $n_{e,t}$, etc)
- No attempt to model parallel variation of T_e, n_e

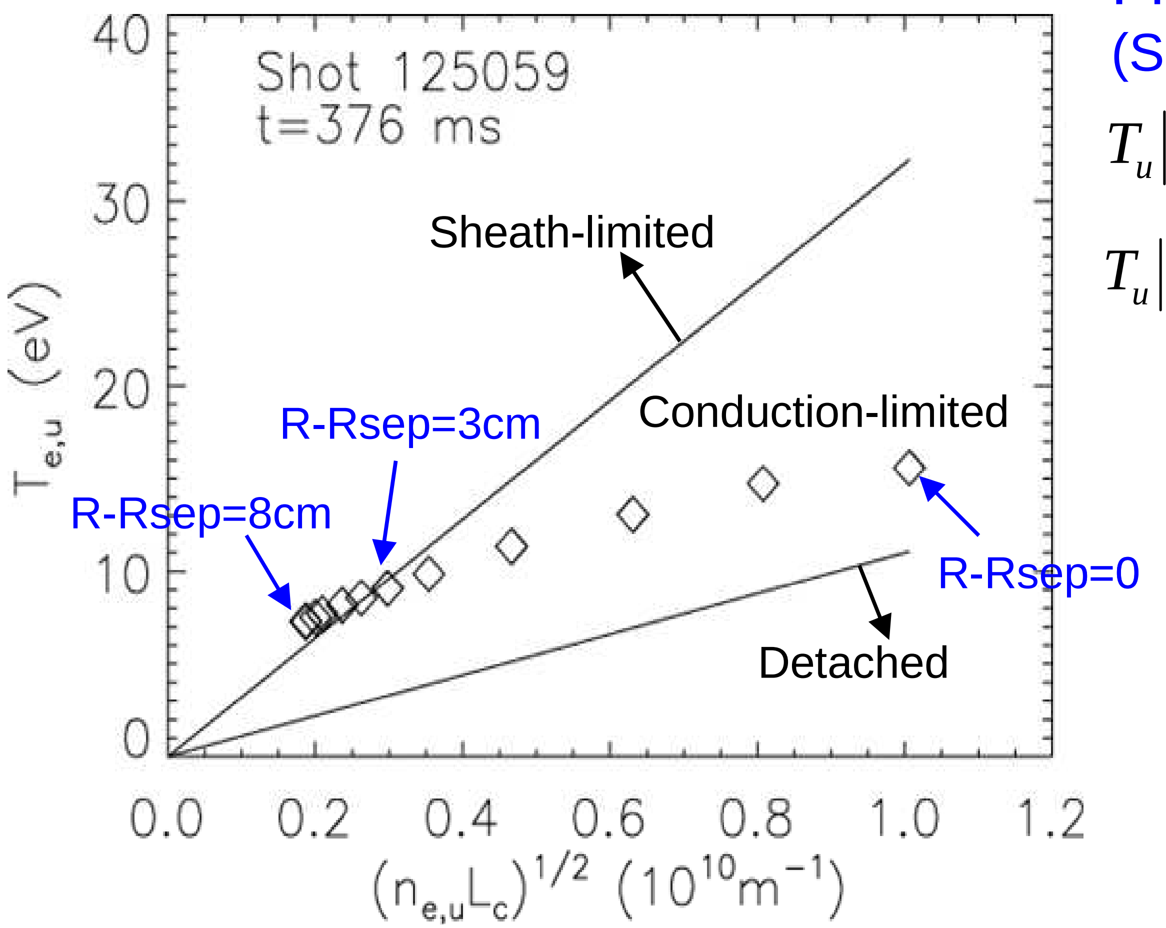
$$2n_t T_t = n_u T_u$$ Pressure balance

$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2}\frac{q_{\parallel} L_c}{\kappa_{0e}}$$ Power balance

$$q_{\parallel} = \gamma n_t k T_t c_{st}$$ Power across the sheath

NSTX Near SOL in conduction-limited regime

SOL plasma regime judged from the upstream temperature and density, T_{eu} and n_{eu}, and the parallel connection length, L_c



From the 2PM analysis

(S.K.Erents, Nucl. Fusion 2000)

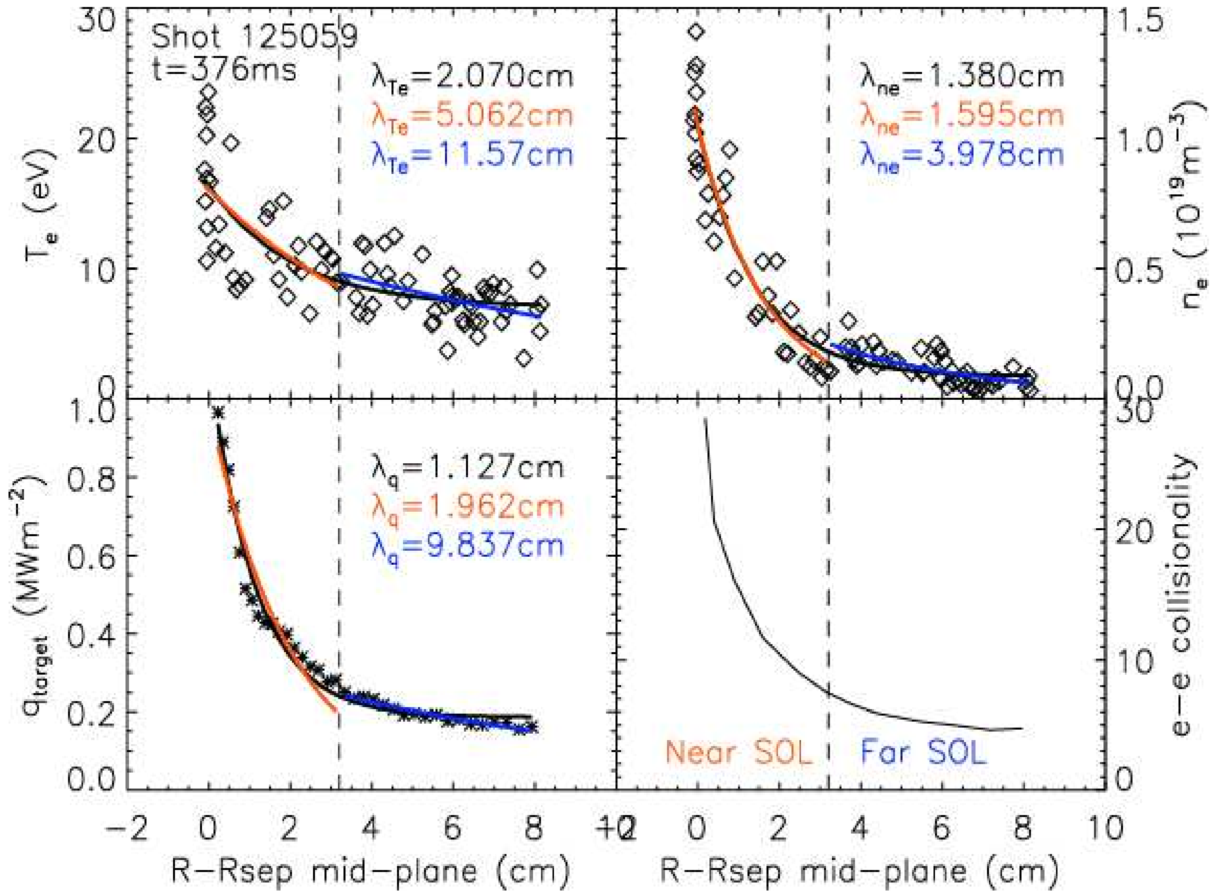
$$T_u\big|_{cond \Leftrightarrow sh} \approx 3.2\times10^{-9}(n_u L_c)^{1/2}$$

$$T_u\big|_{cond \Leftrightarrow \det} \approx 1.1\times10^{-9}(n_u L_c)^{1/2}$$

Near SOL (R-Rsep $\leq$ 3cm)
conduction-limited regime

Far SOL (R-Rsep $\geq$ 3cm)
sheath-limited regime

NSTX SOL parameter profiles



§ T_e, n_e, and v^*_{ee} : probe measurement

§ q_{target} : IR meausrement

§ All profiles mapped to the mid-plane

§ All profiles have long tail in the far SOL
Offset exponential fitting to the whole profile

Relation between λ_q and λ_{Te} in Near SOL (conduction-limited regime)

|| electron conduction with $\nabla_{||} T_e$

$$T_e \sim \left(\frac{7}{2} \frac{q_{||} L_c}{\kappa_0} \right)^{2/7}$$

(1) Assume simple exponential profiles

$$T_e = T_{e0} \exp\left(-\frac{R - R_{sep}}{\lambda_{Te}} \right)$$

$$q_{target} = q_0 \exp\left(-\frac{R - R_{sep}}{\lambda_q} \right)$$

$$\lambda_{Te} = \frac{7}{2} \lambda_q$$

Conventional relation

(2) Assume offset exponential profiles

$$T_e = T_{e1} + T_{e0} \exp\left(-\frac{R - R_{sep}}{\lambda_{Te}} \right)$$

$$q_{target} = q_1 + q_0 \exp\left(-\frac{R - R_{sep}}{\lambda_q} \right)$$

$$\lambda_{Te} = \frac{7}{2} \lambda_q \left(\frac{T_e - T_{e1}}{T_e - C q_1 T_e^{-5/2}} \right) \qquad C = \frac{7}{2} \frac{L_c}{\kappa_0}$$

Additional factor introduced

Near SOL widths appear to follow classical relationship

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(1) Fitting to Simple exponential

Observed ratio		Predicted ratio
$\lambda_{Te}/\lambda_q \sim 2.5$	↔ ~33% different	$\lambda_{Te}/\lambda_q = 3.5$

(2) Fitting to Offset exponential

Observed ratio		Predicted ratio
$\lambda_{Te}/\lambda_q \sim 1.84$	↔ ~18% different	$\lambda_{Te}/\lambda_q = 2.2$

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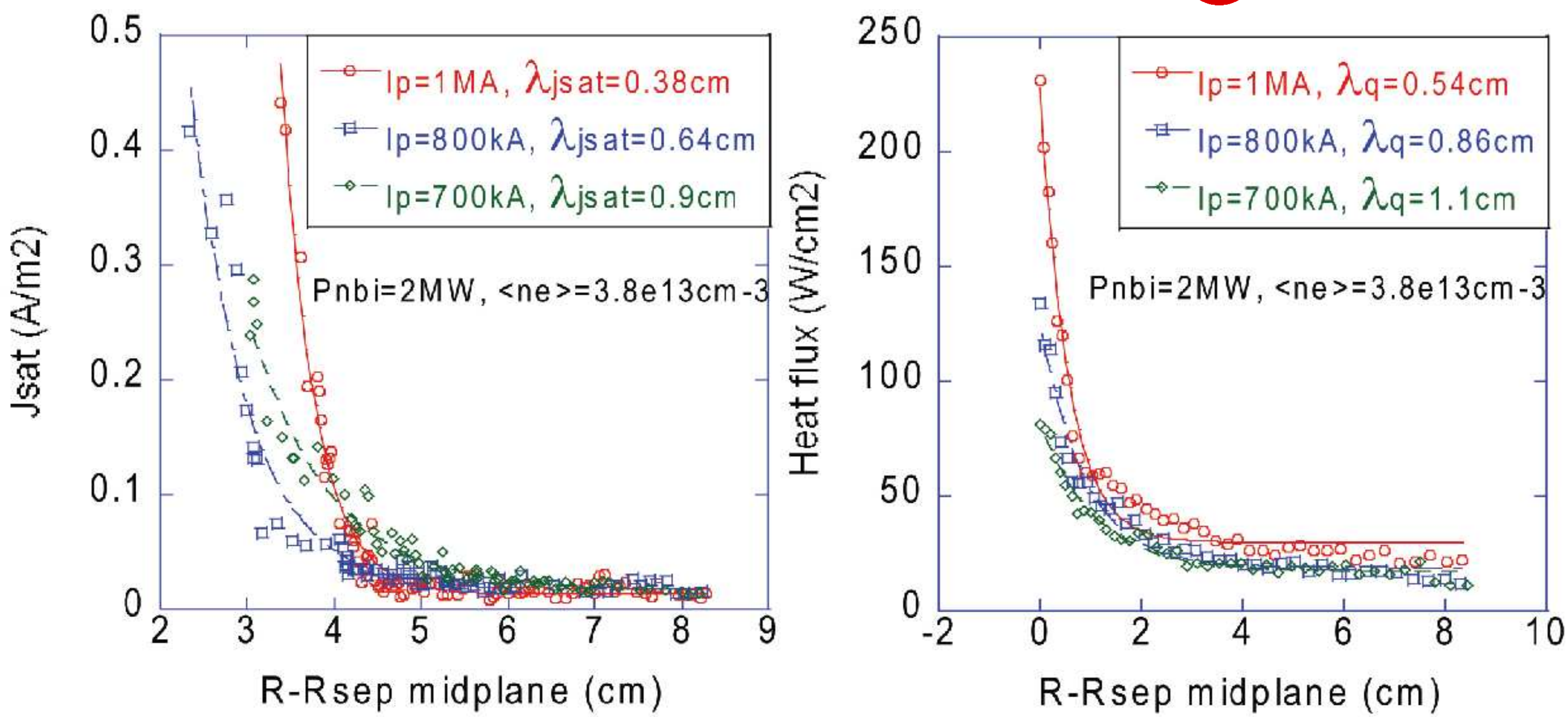
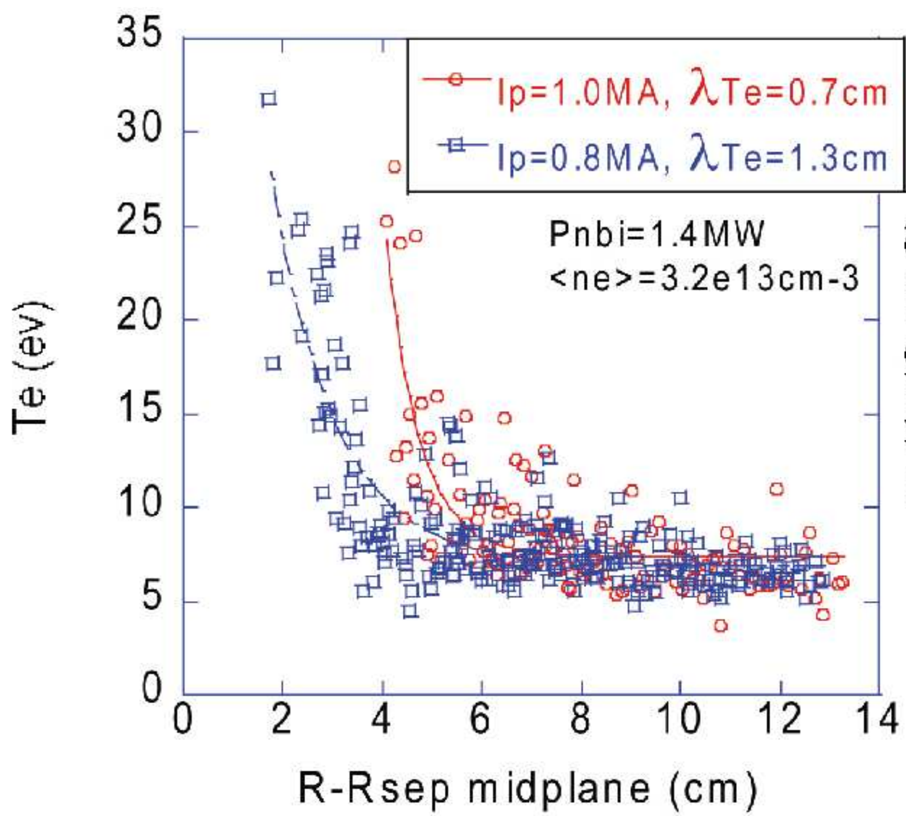
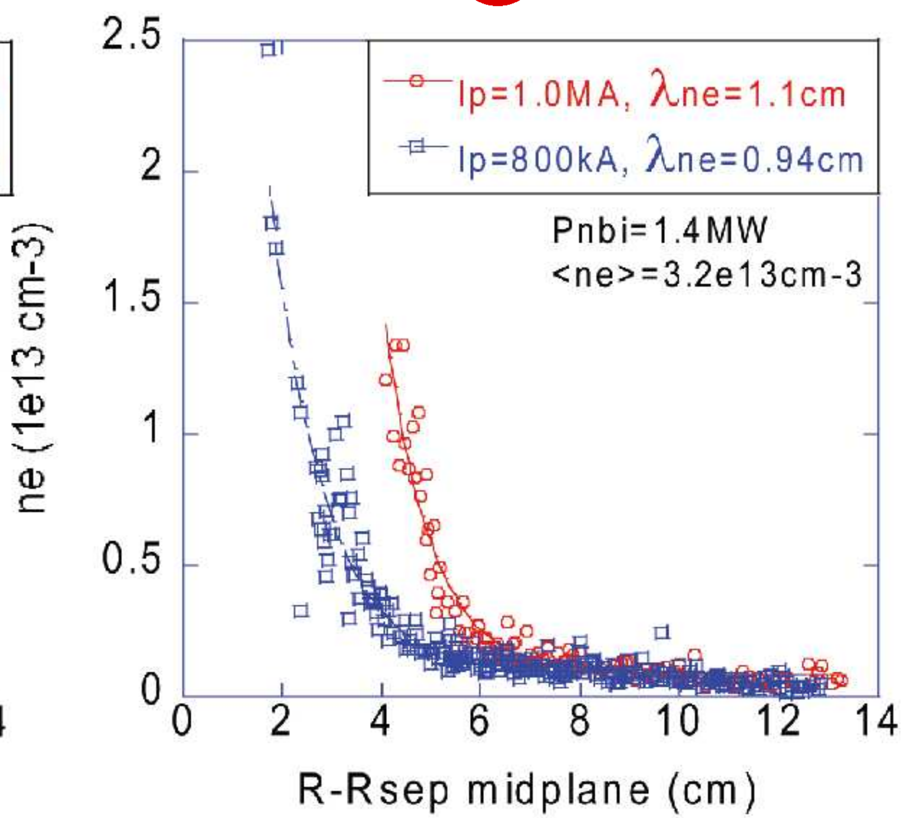
Both λ_{jsat} and λ_q increase with decreasing I_p



- j_{sat} profiles from the fast probe and $q_\perp$ profiles from the IR camera
- The apparent radial 'shift' of j_{sat} profiles with respect to each other thought to be due to the uncertainty in magnetic equilibrium reconstruction

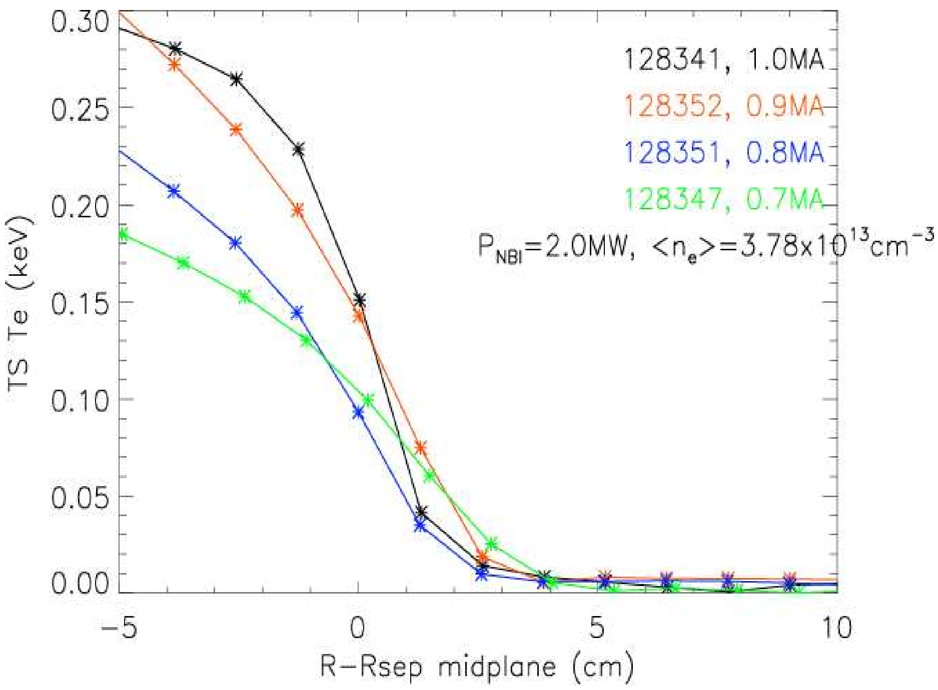
λ_{Te} increases and λ_{ne} stays similar with decreasing I_p

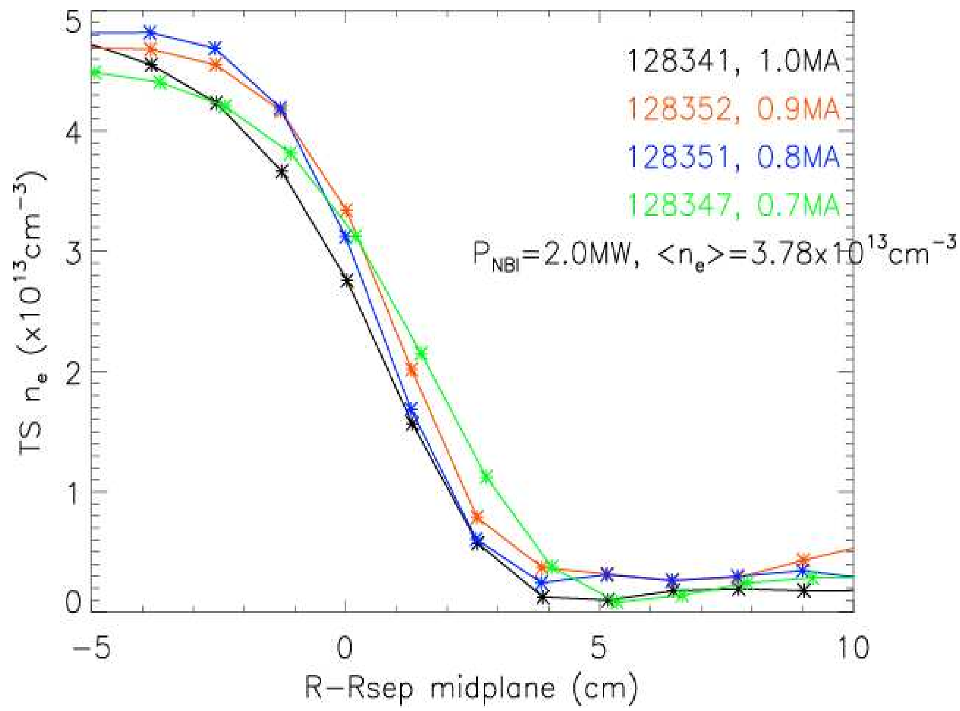




- T_e and n_e profiles from the fast probe
- Large $R\text{-}R_{sep}$ values for the profiles & the respective profile 'shift' is believed to be due to uncertainty in magnetic reconstruction

TS profiles indicate: $I_p \downarrow$ $\lambda_{Te} \uparrow$ & λ_{ne} unchanged





§ However, TS data points too sparse, does not allow for decay length fitting
Work underway to ensemble TS data points as a function of $R-R_{sep}$ to evaluate decay lengths

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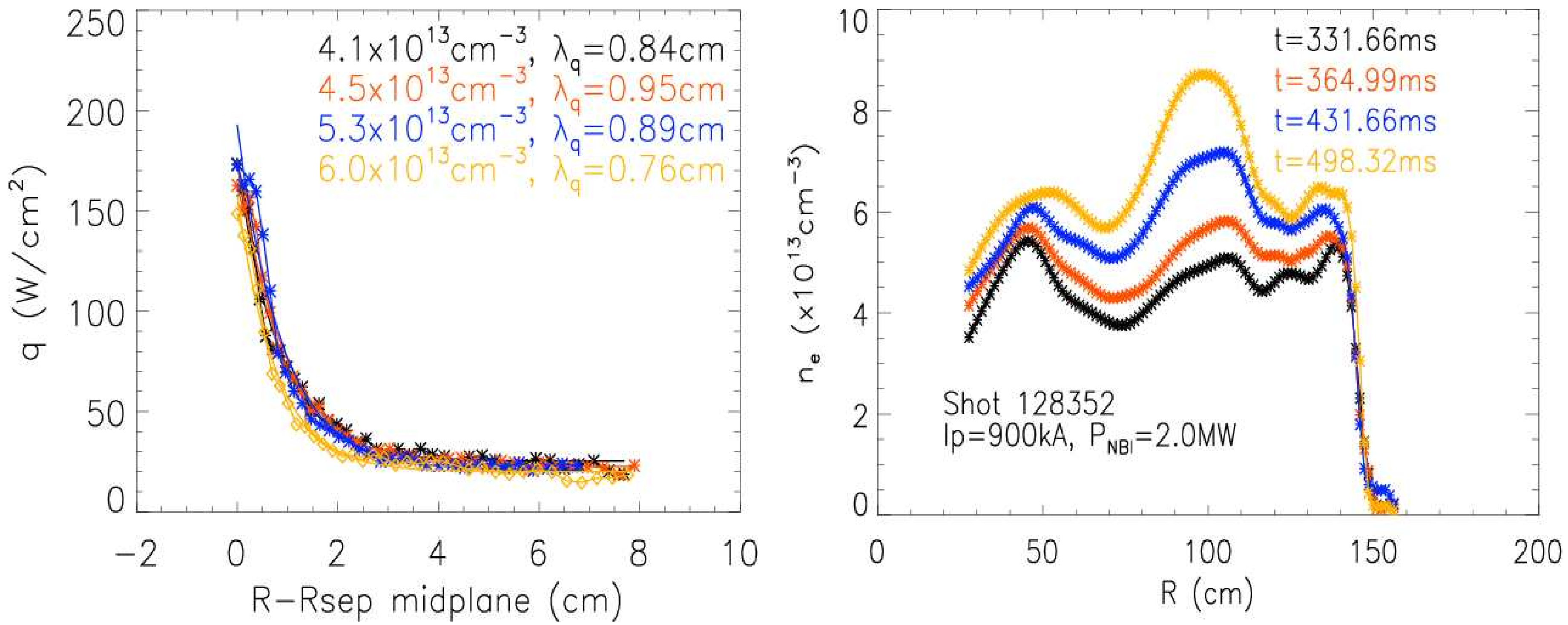
λ_q stays the same with <n_e> increase by 50%



§ $q_\perp$ profiles from the IR camera
§ n_e profiles from TS

TS profiles indicate: λ_{Te} & λ_{ne} unaffected by <n_e> scan

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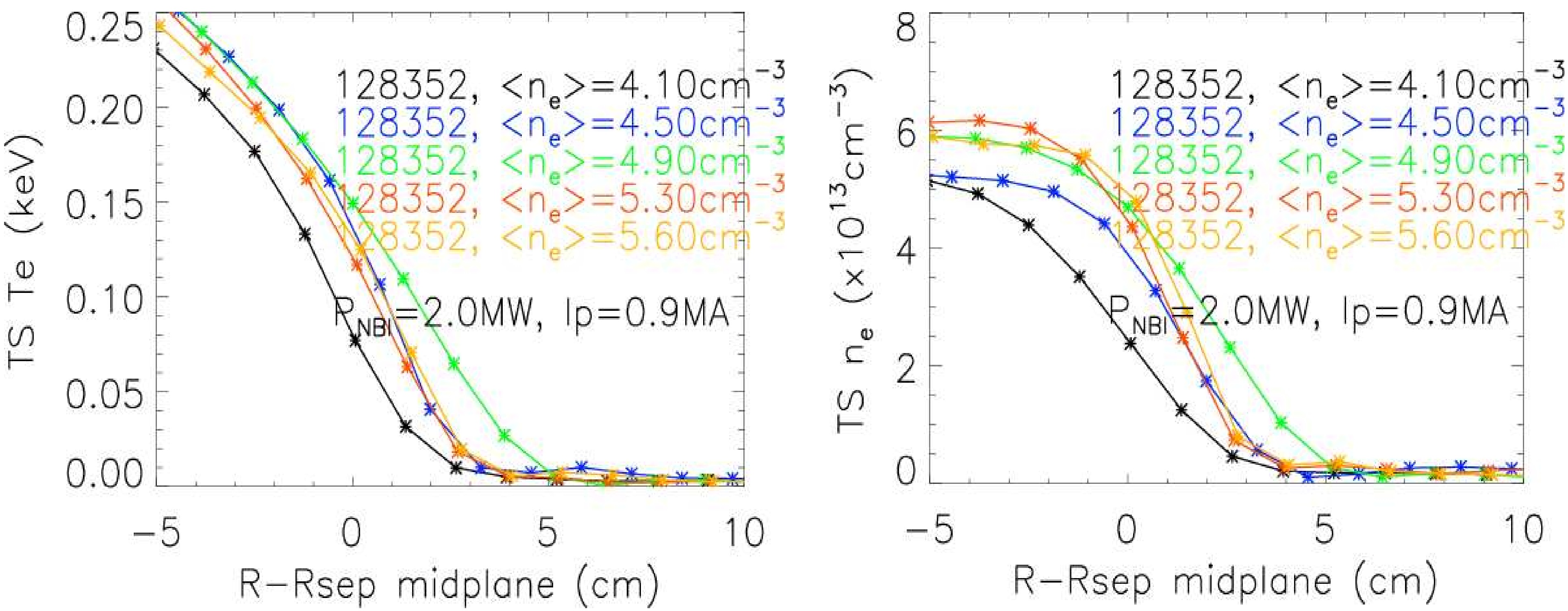
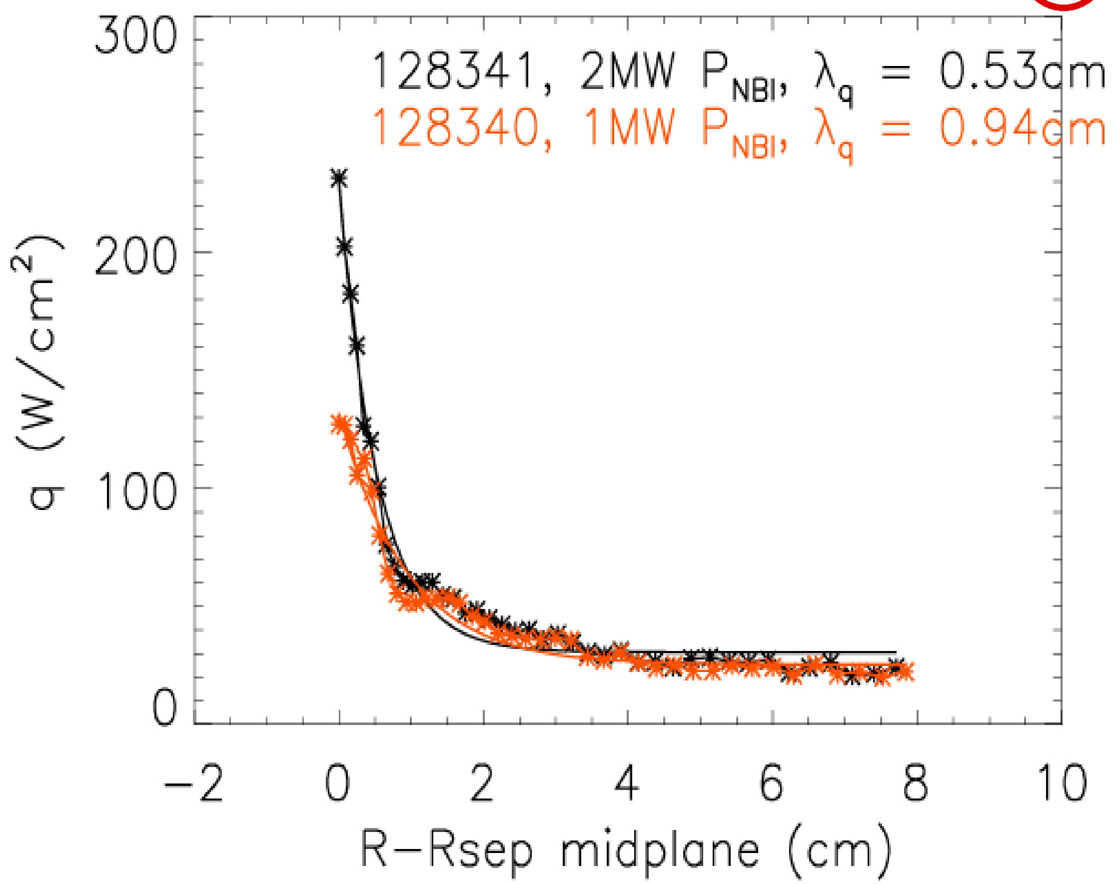


- Although some decay length variation seen, no consistent trend observed
- Other datasets with different density variation (higher than a factor of 2, but with no IR heat flux data) show no change in λ_{Te} & λ_{ne}

λ_q decreases with increasing P_{NBI}



- $q_{\perp}$ profiles from the IR camera
- No fast probe data obtained for power scan

TS profiles indicate: $P_{NBI} \uparrow$ $\lambda_{Te} \uparrow$ & λ_{ne} unchanged

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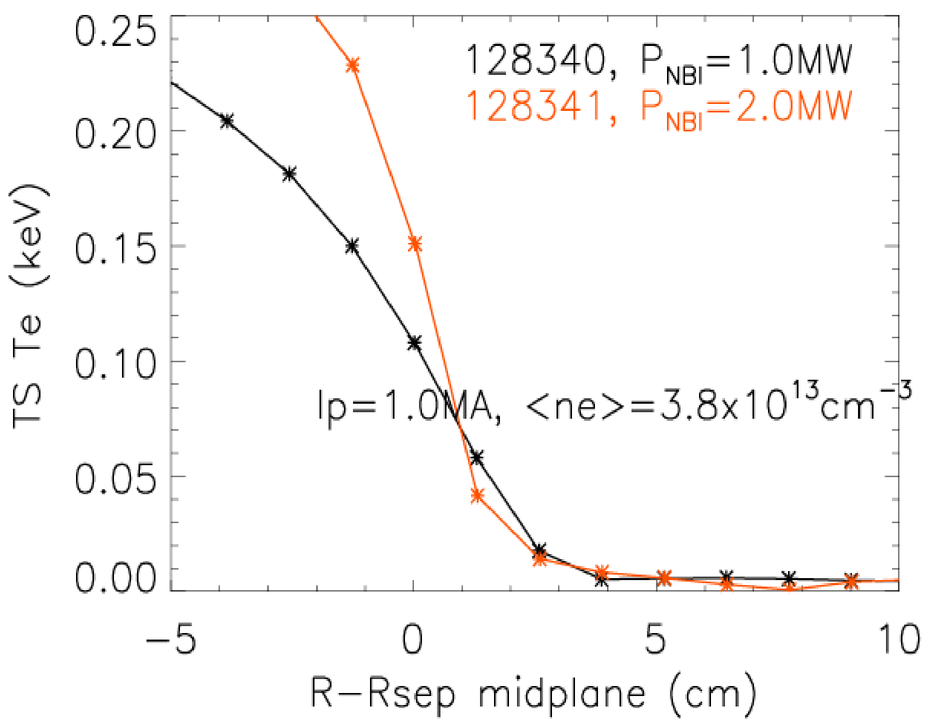

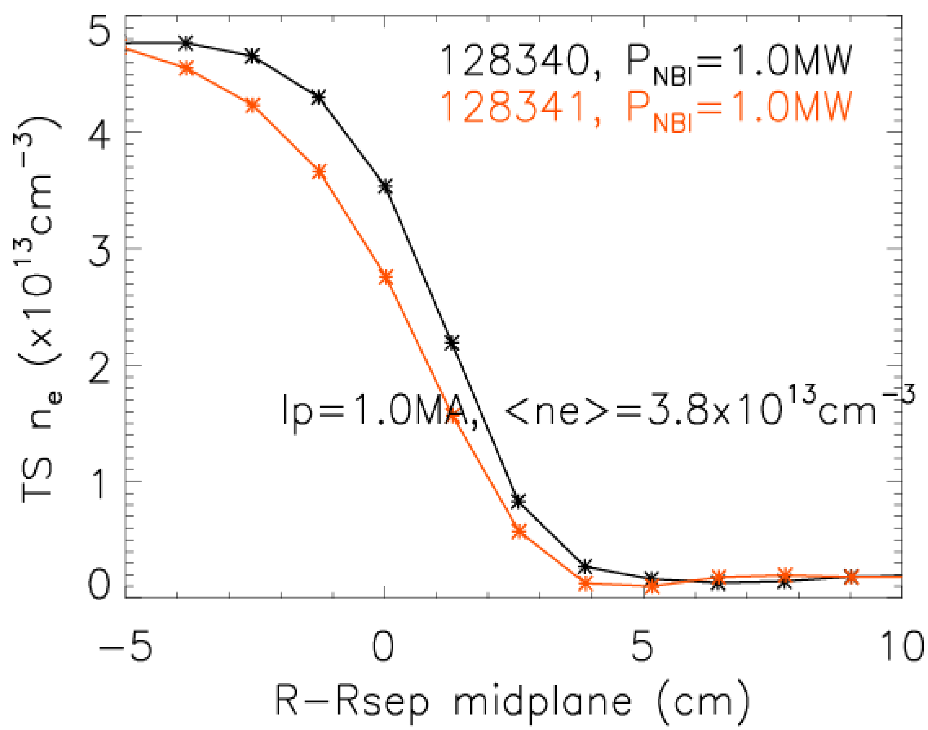

§ This trend is also shown in more datasets

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Qualitative comparison with H-mode SOL width scaling laws from conventional tokamaks

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$$\lambda_{Te} \propto n_e^{0.92\pm0.18} I_p^{-1.79\pm0.27} (P_{tot} - P_{rad})^{-0.63\pm0.09}$$

from AUG[1]

$$\lambda_{ne} \propto n_e^{1.11\pm0.13} I_p^{-2.25\pm0.16}$$

from AUG[1]

$$\lambda_q \propto B_t^{-0.93} q_{95}^{0.41} P_{SOL}^{-0.48} n_{e,u}^{0.15}$$

from JET[2]

- λ_{Te} , λ_{ne} , and λ_q dependences on I_p and power consistent with scaling laws
- λ_q dependence on density consistent with the scaling law
- λ_{Te} and λ_{ne} dependence on density shows different trend from scaling laws

[1]K. McCormick, JNM 266-269 (1999) 99
[2]W.Fundamenski, NF 44 (2004) 20

Summary and conclusions

- NSTX near SOL plasma is conduction dominated
- Relation between λ_{Te} and λ_q in near SOL plasma follows classical prediction
- Confirmed dependence of λ_q, λ_{Te}, λ_{jsat}, and λ_{ne} on I_p, power, and $<n_e>$
  - negative dependence on I_p and power
  - no dependence on $<n_e>$
  - λ_q variation appears to be driven primarily by λ_{Te} variation
- λ_{ne} remains unchanged by any parameter scan
- Comparison of experimental data with H-mode scaling laws from conventional tokamaks
  - λ_{Te} , λ_{ne} , and λ_q dependences on I_p and power consistent with scaling laws
  - λ_q dependence on density consistent with the scaling law
  - λ_{Te} and λ_{ne} dependence on density shows different trend from scaling laws