NSTX

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Dependence of SOL widths on plasma parameters in NSTX

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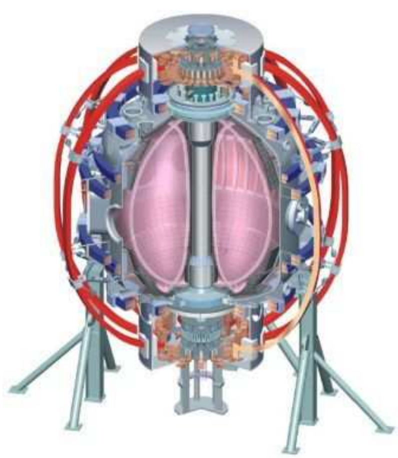
November 19, 2008



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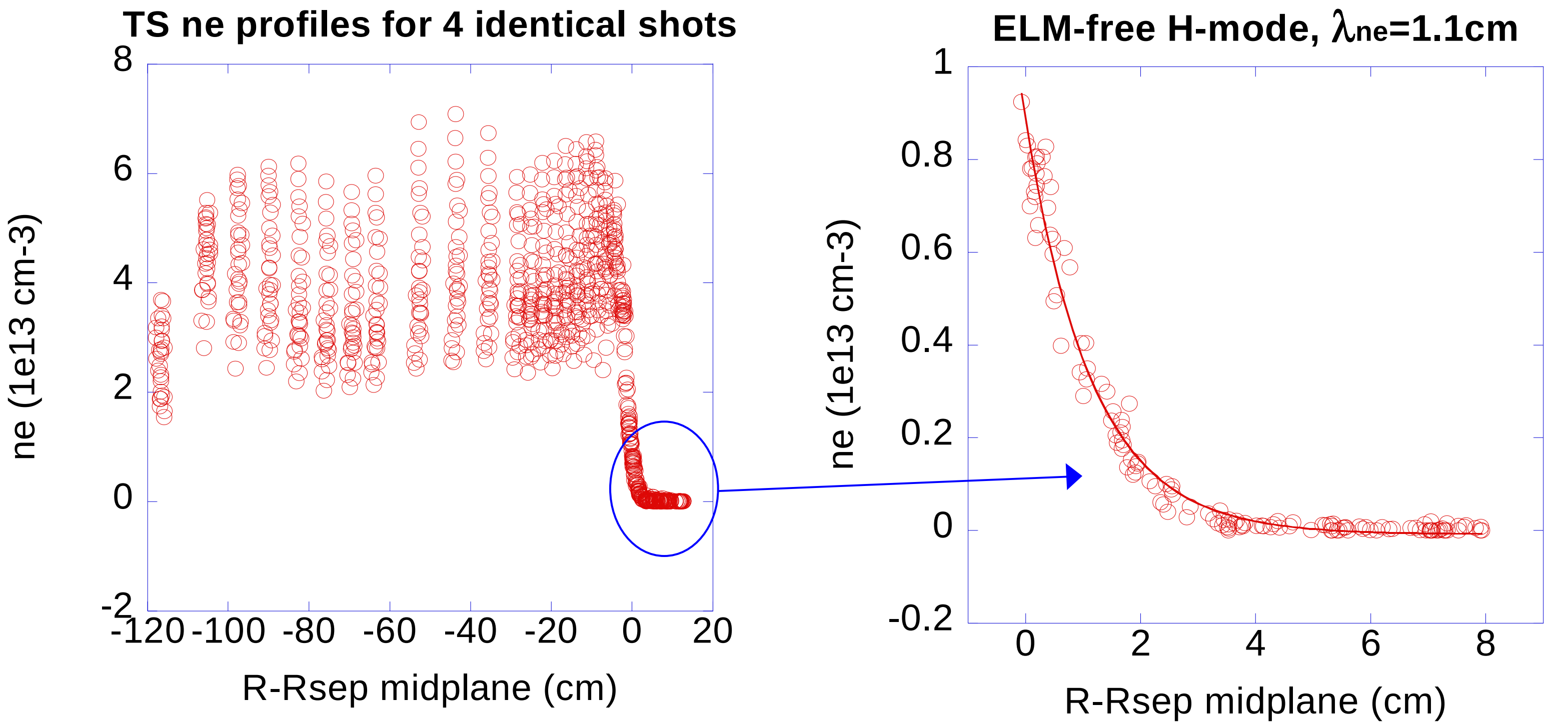
Dependence of SOL widths on nebar

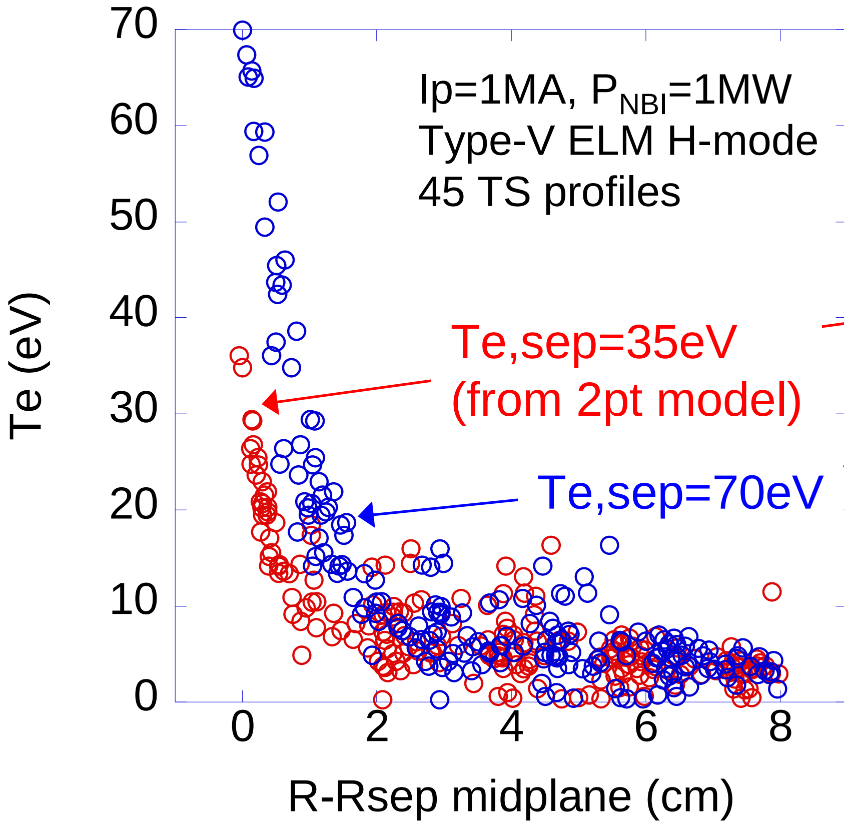
Edge density profile is 'fixed' during the H-mode density ramping period

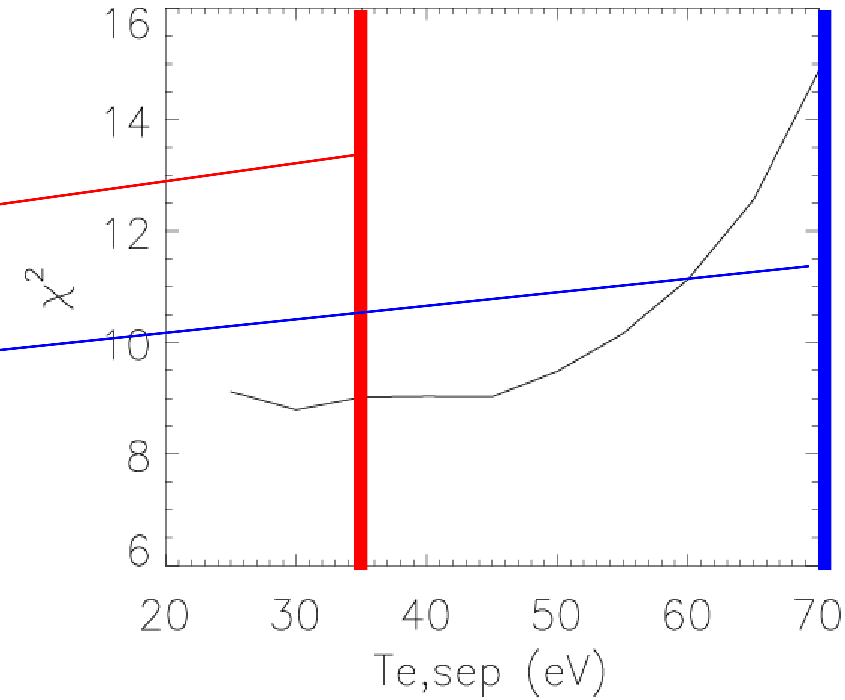


- $T_{e,sep}$ estimated from 2 point model (*i.e*. from power balance)
- Re-align TS profiles as a function of R-Rsep with separatrix location determined by $T_{e,sep}$
- $n_{e,sep}$ is fixed irrespective of nebar

This enables us to ensemble TS profiles at different time slices for identical H-mode shots to construct a profile with higher spatial resolution

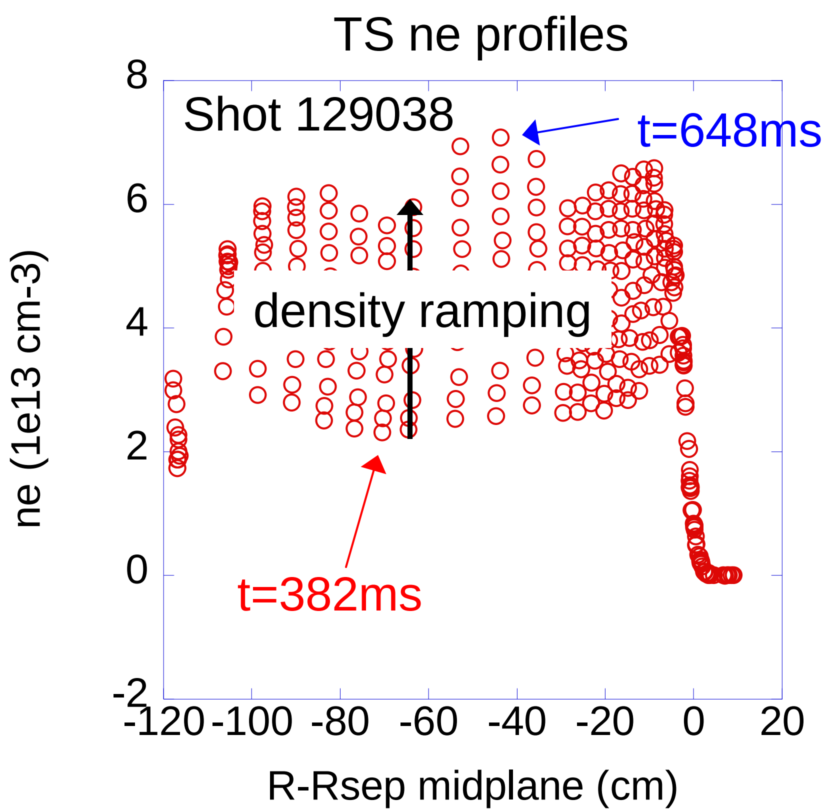
Reliability of ensembled TS profiles

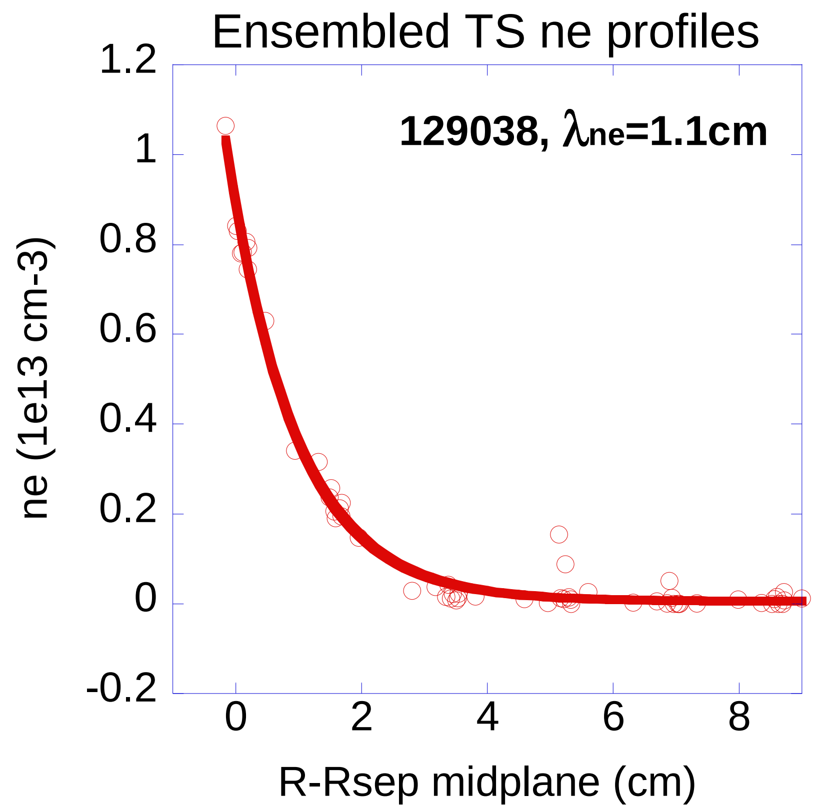




- χ^2 stays low up to $T_{e,sep}$=45eV ($T_{e,sep}$=35eV from 2-point model)
- For $T_{e,sep}$ > 45eV, ensembled profile becomes more scattered
  → $T_{e,sep}$=35eV appears to be in right ball park

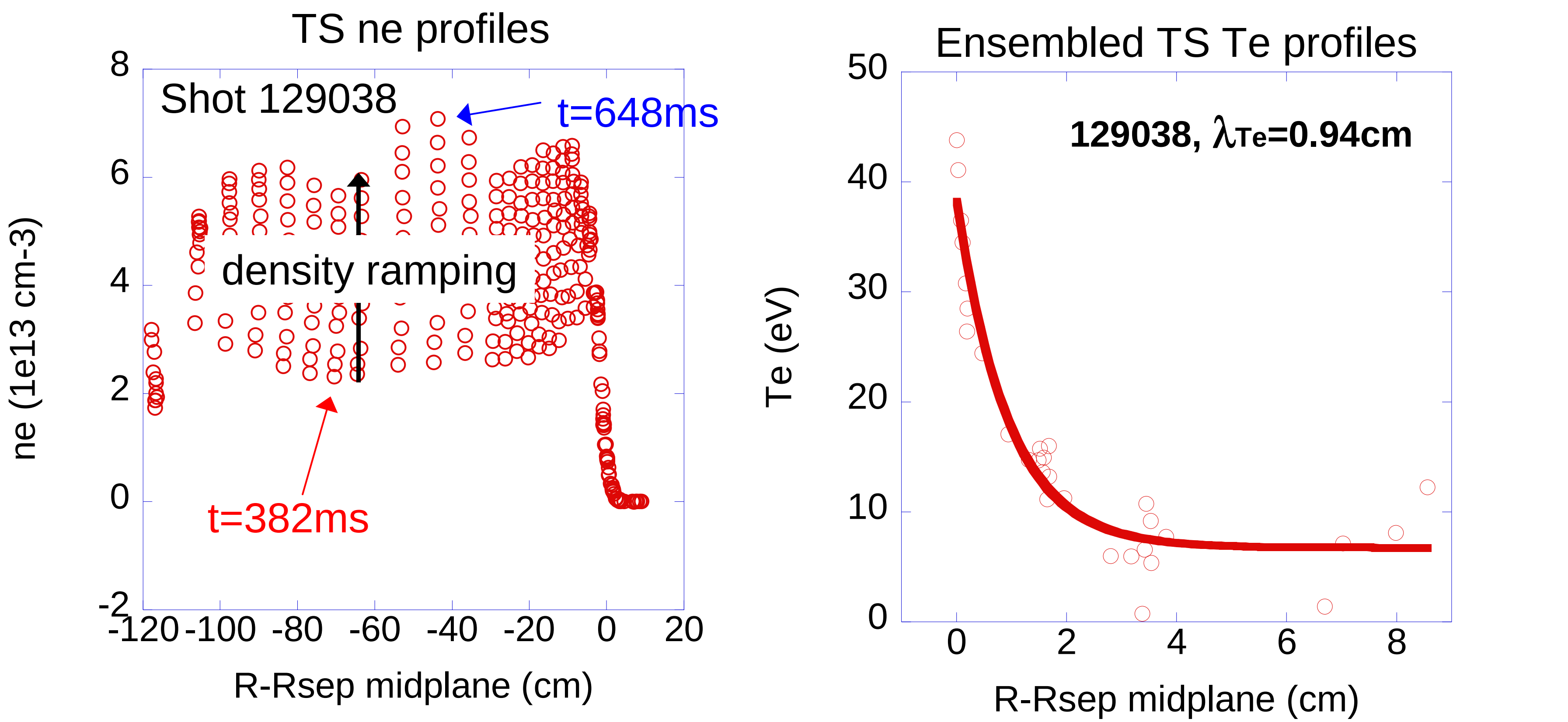
Density scan in ELM-free H-mode: λ_{ne} stays constant





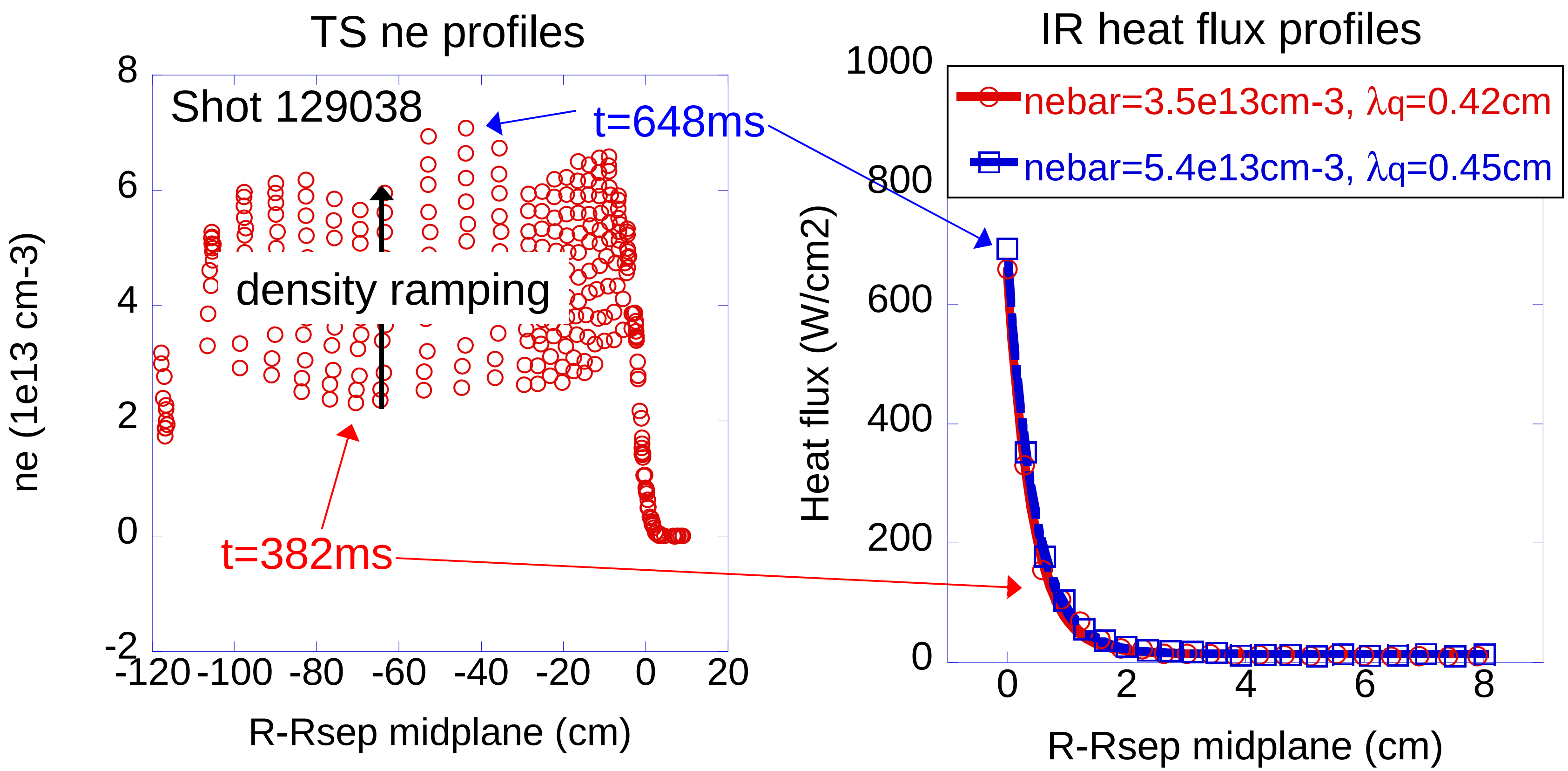
- nebar continuously rises during the H-mode, by a factor of ~2, with $n_{e,sep}$ fixed
- λ_{ne} stays constant at ~1.1cm

Density scan in ELM-free H-mode: λ_{Te} stays constant



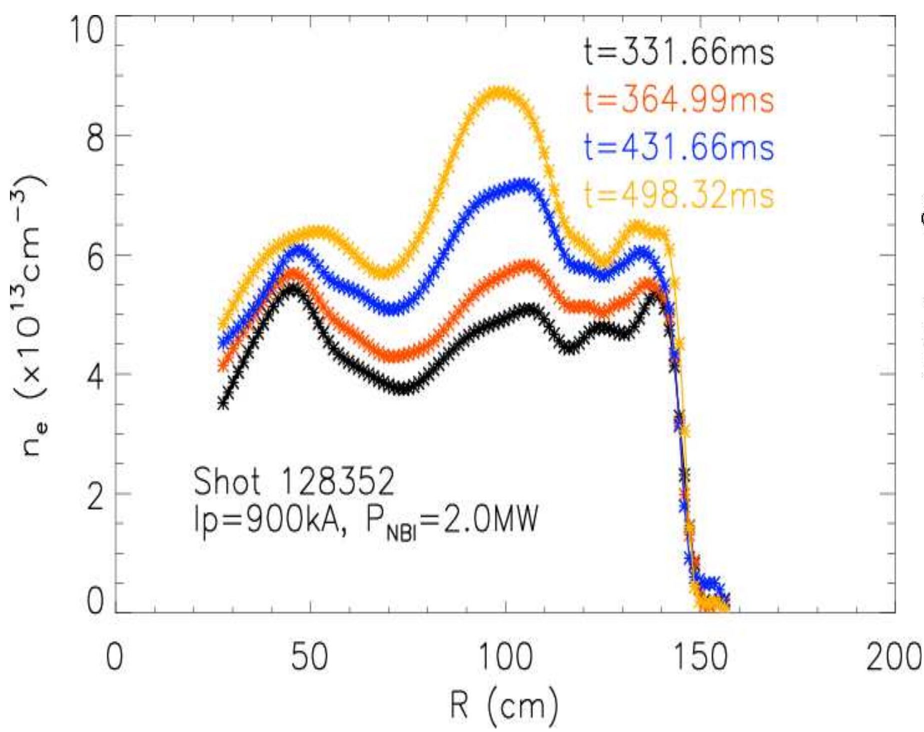
- nebar continuously rises during the H-mode, by a factor of ~2, with $n_{e,sep}$ fixed
- λ_{Te} stays constant at ~0.9cm

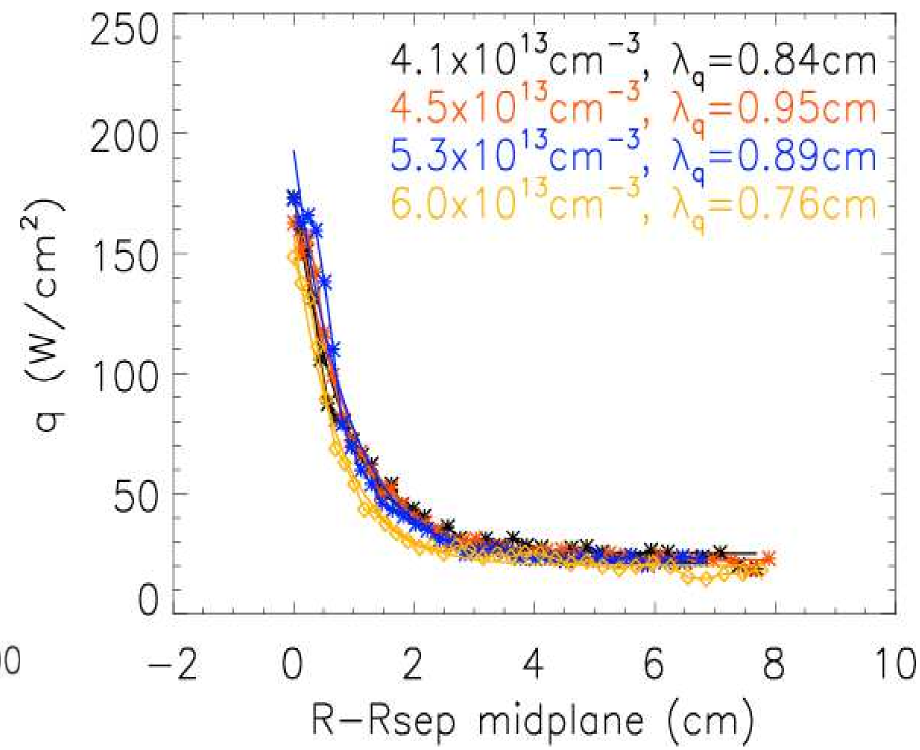
Density scan in ELM-free H-mode: λ_q stays constant



- nebar continuously rises during the H-mode, by a factor of ~2, with $n_{e,sep}$ fixed
- λ_q stays constant at 0.4-0.5cm

Density scan result for Type-V ELMy H-mode: λ_q stays constant

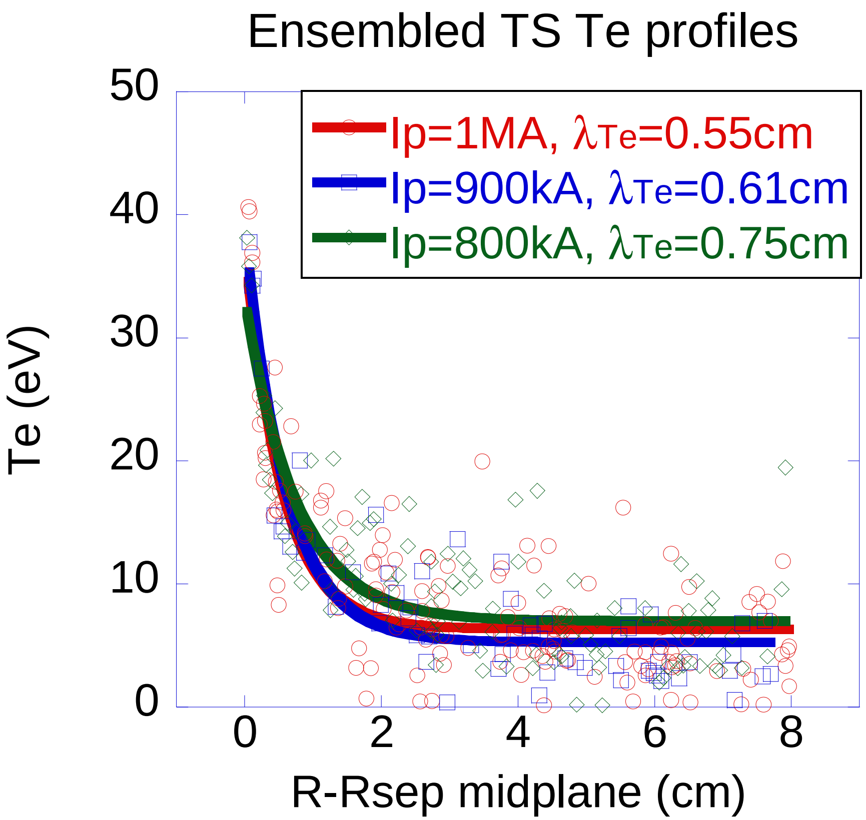


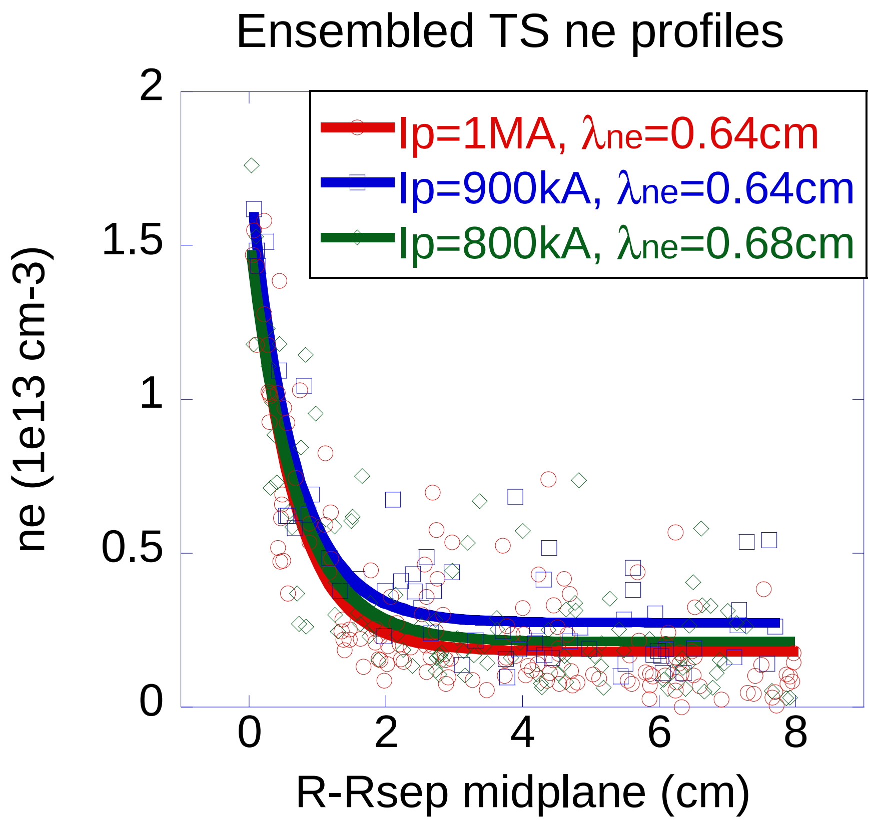


- nebar increase by ~40% → λ_q stays at 0.8-0.9cm
- λ_{Te} and λ_{ne} also stay constant irrespective of nebar

Dependence of SOL widths on I_p and power

λ_{Te} from TS measurement decreases with increasing Ip while λ_{ne} stays constant, in Type-V ELMy H-mode

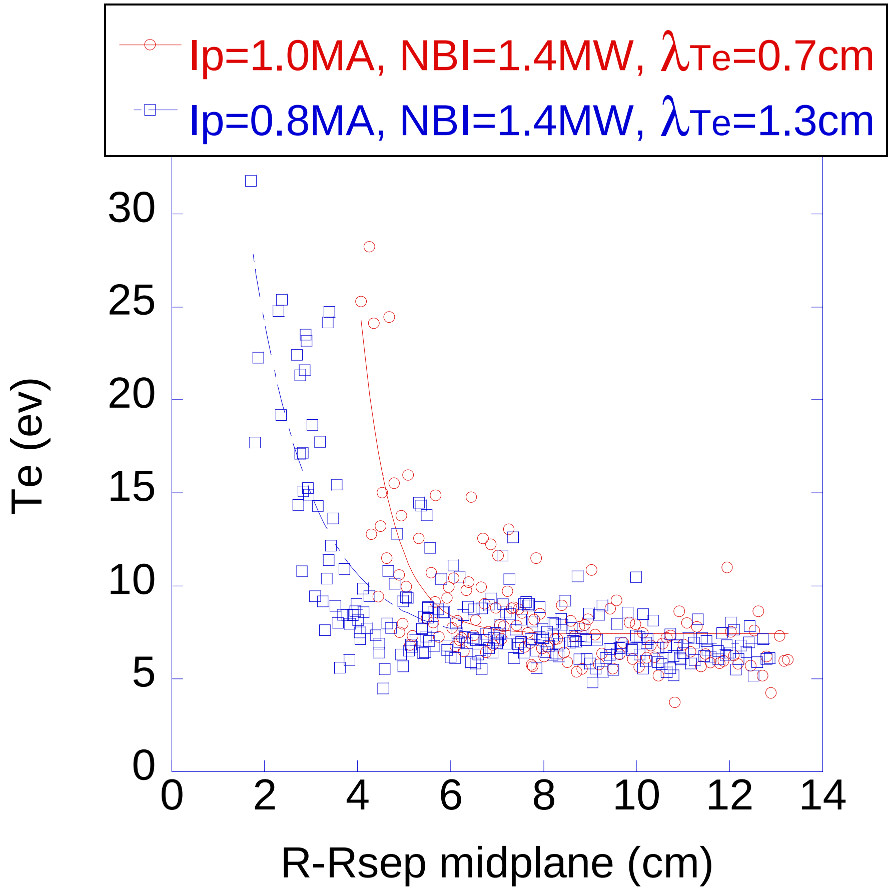


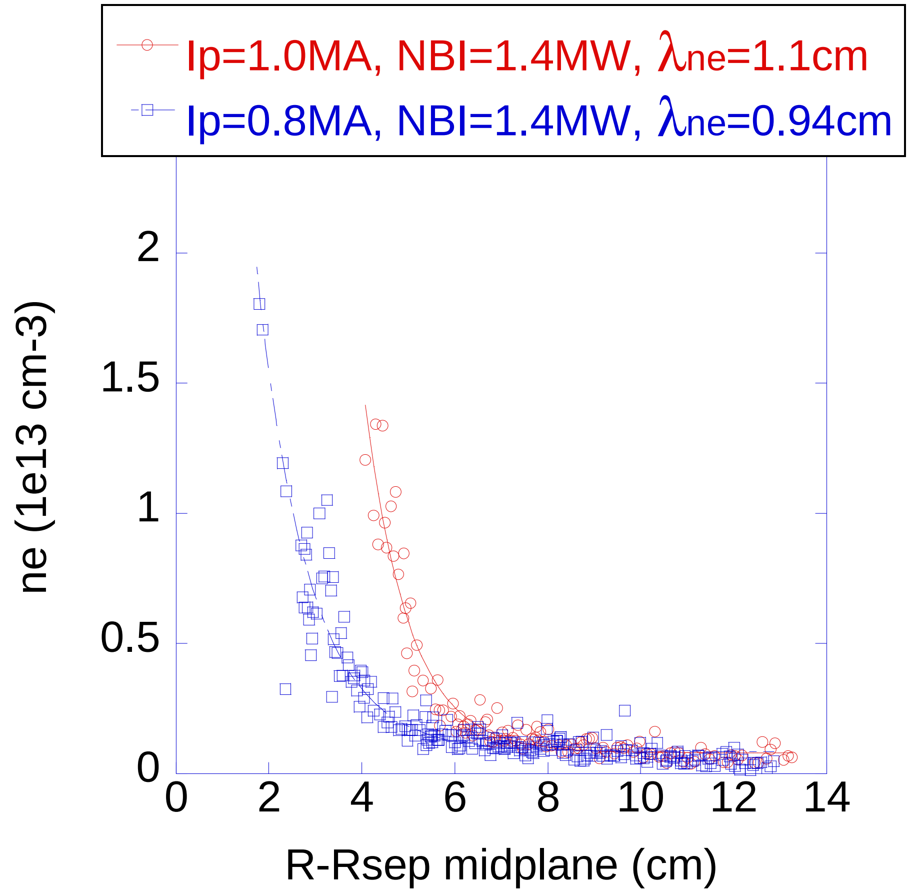


Ip: 1MA $\rightarrow$ 800kA

- λ_{Te} : 0.55cm $\rightarrow$ 0.75cm
- λ_{ne} : staying at ~0.65cm

λ_{Te} from probe measurement decreases with increasing Ip while λ_{ne} stays constant, in Type-V ELMy H-mode





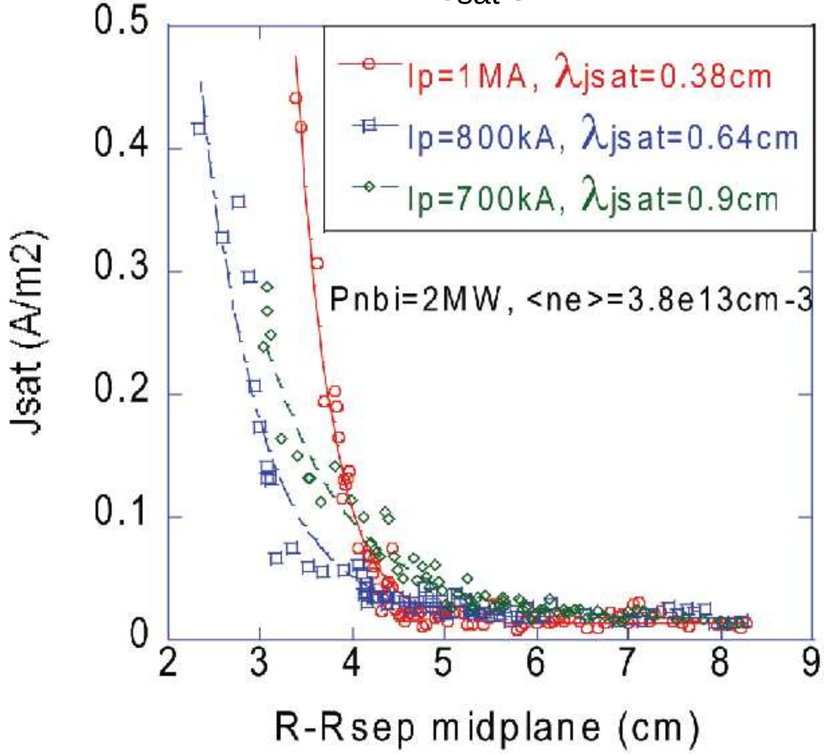
Ip: 1MA → 0.8MA

λ_{Te} increases by a factor of ~2

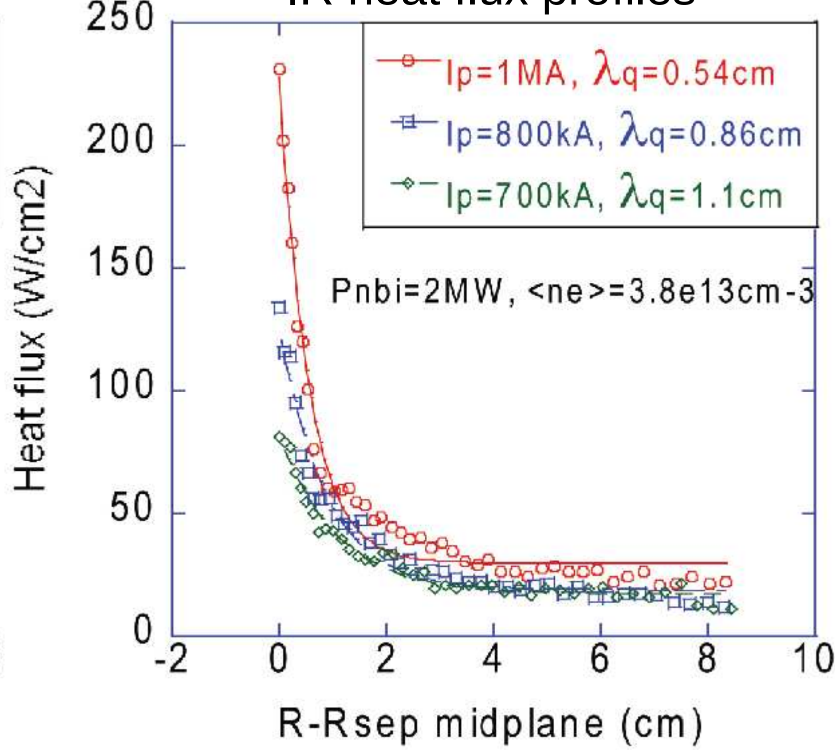
- λ_{ne} remains unchanged

λ_{jsat} and λ_q decrease with increasing Ip in Type-V ELMy H-mode

Probe j_{sat} profiles



IR heat flux profiles

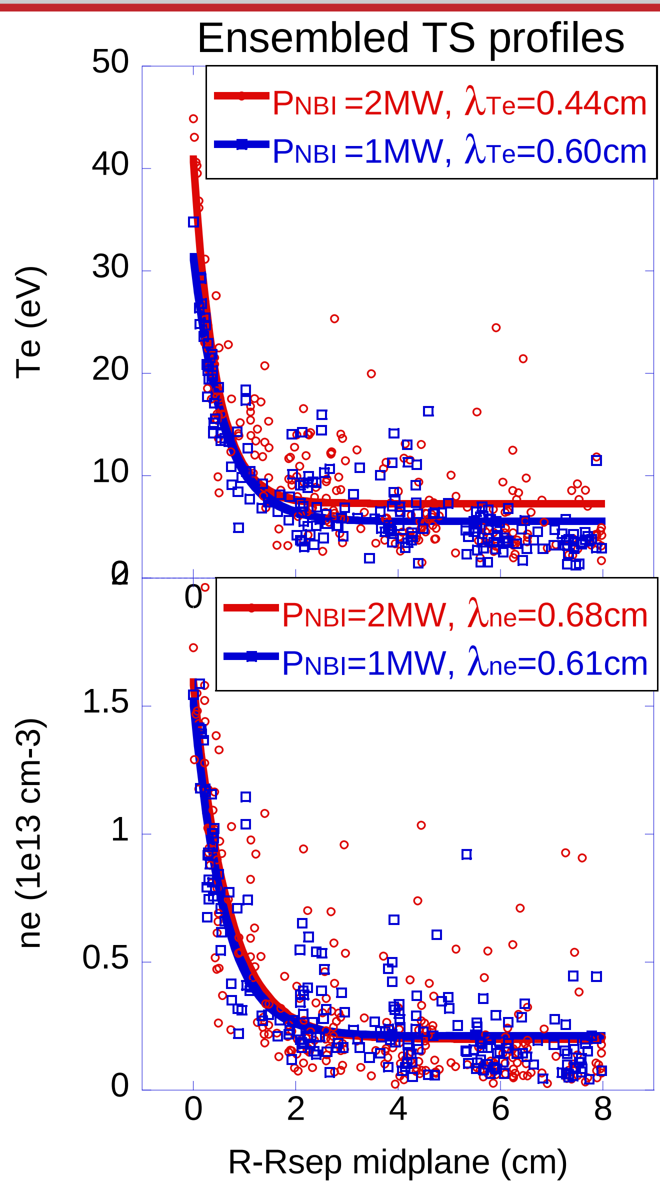


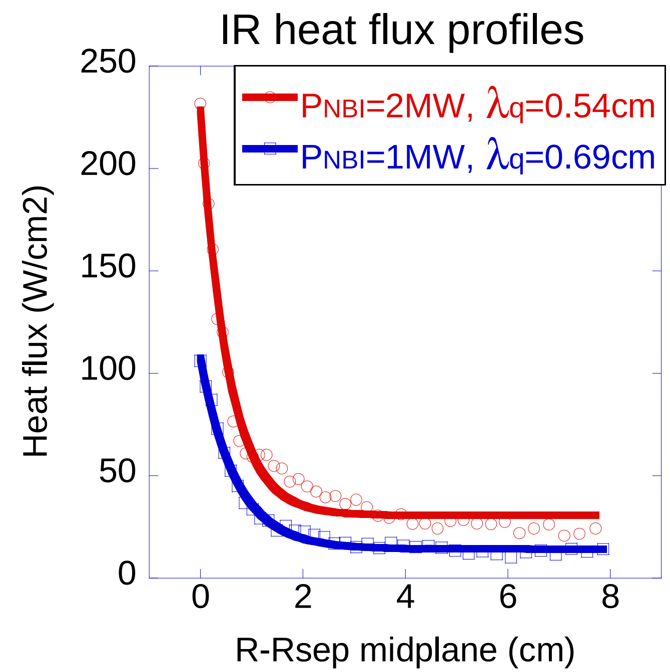
R-Rsep for fast probe J_{sat} data is from equilibrium reconstruction

Ip: 1MA $\rightarrow$ 700kA

- λ_{jsat} : 0.4cm $\rightarrow$ 0.9cm
- λ_q : 0.5cm $\rightarrow$ 1.1cm

Power scan result: λ_{Te} and λ_q decrease with increasing power while λne stays constant, in Type-V ELMy H-mode





P_{NBI}: 1MW → 2MW

- λ_{Te} : 0.6cm → 0.44cm
- λ_{ne} : staying at ~0.65cm
- λ_q : 0.69cm → 0.54cm

Comparison of observed dependences with H-mode SOL width scaling laws from conventional tokamaks

$$\lambda_{Te} \propto n_e^{0.92\pm0.18} I_p^{-1.79\pm0.27} (P_{tot} - P_{rad})^{-0.63\pm0.09}$$ from ASDEX-U[1]

$$\lambda_{ne} \propto n_e^{1.11\pm0.13} I_p^{-2.25\pm0.16}$$ from ASDEX-U[1]

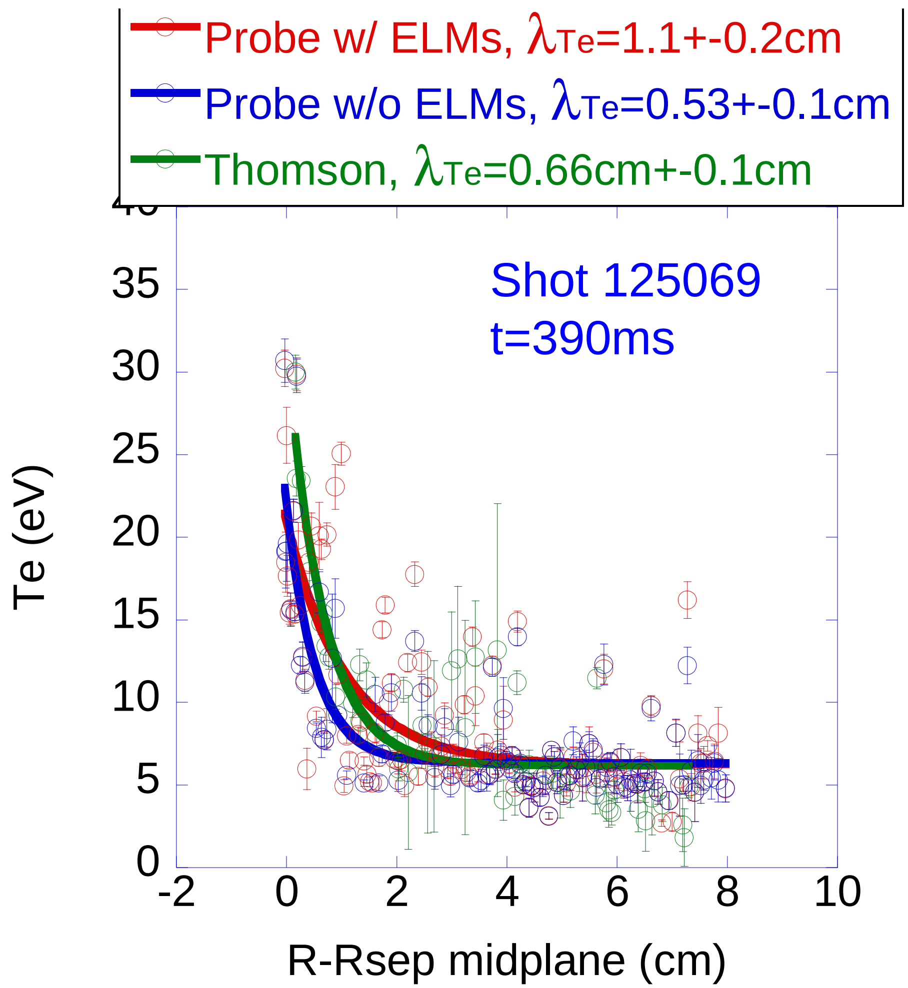
$$\lambda_q \propto B_t^{-0.93} q_{95}^{0.41} P_{SOL}^{-0.48} n_{e,u}^{0.15}$$ from JET[2]

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

[1]K. McCormick, J. Nuclear Material 266-269 (1999) 99
[2]W.Fundamenski, Nucl. Fusion 44 (2004) 20

Role of ELMs in determining SOL widths

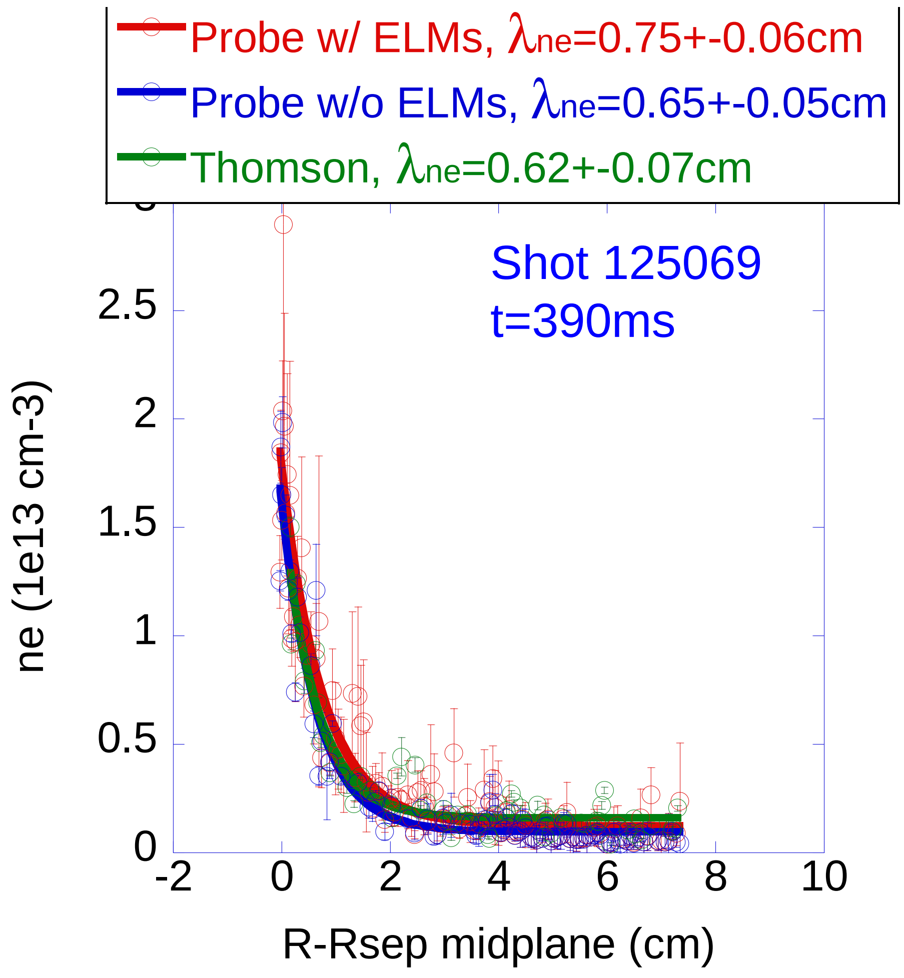
λ_{Te} is strongly affected by ELMs and turbulent blobs



- Probe measurement is continuously affected by ELMs and blobs
  - → measured Te shows high scatter
  - → Te SOL width broadens
- Probe I-V data with ELM affected portions removed
  - → re-process probe data
  - → Te SOL width becomes narrower
- TS measurement is instantaneous
  - → misses many ELM filaments in the near SOL
  - → effectively represents inter-ELM profile with narrower λ_{Te}
  - → Probe λ_{Te} (with ELMs and blobs removed) similar to TS λ_{Te}

T_e profile is highly affected by ELMs and turbulent blobs

λ_{ne} is little affected by ELMs and turbulent blobs



- λ_{ne} from probe is only a little broader than λ_{ne} from TS
- Probe data 'without ELMs and bobs' produces only a little narrower λ_{ne}, compared with λ_{ne} 'with ELMs and blobs'
- Change in Te affects density only to a limited extent because of stronger contribution of jsat (*i.e.*, $n_e \propto I_{sat}^{+} / \sqrt{T_e}$)

'Time-average' density profile is not sensitive to ELMs and turbulent blobs

ELMs may be responsible for broad Te and heat flux profiles

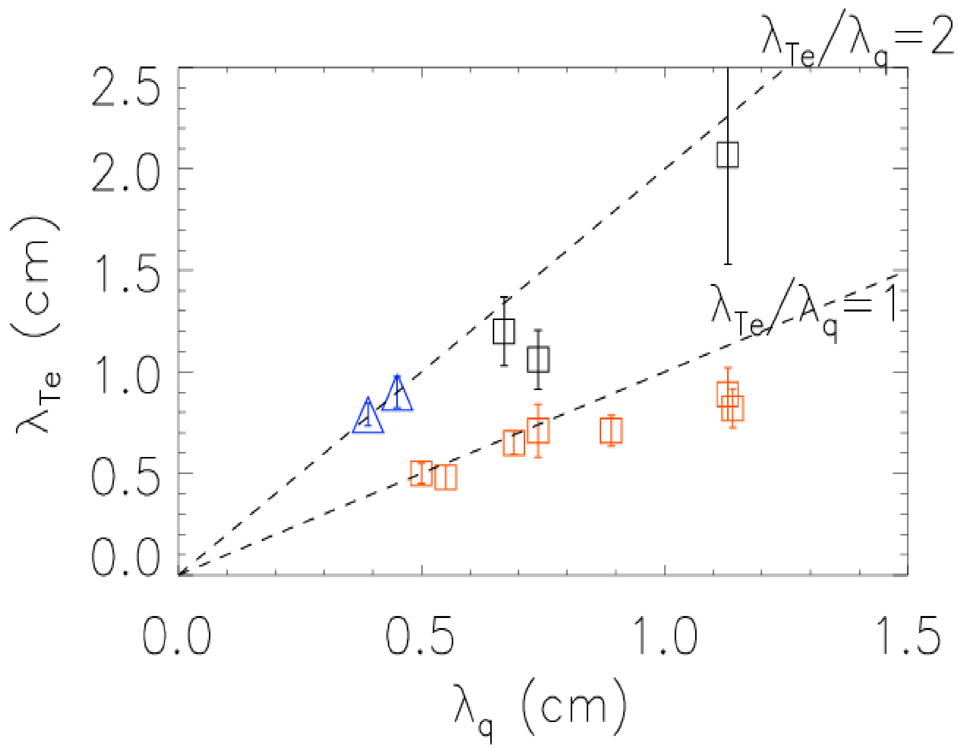
1. Characteristics of Type-V ELMs[1]:
n=3-4, L_Φ~0.15m, L_r~0.1m, L_z~0.1m,
v_Φ ~8.6km/s, v_r~0.2km/s
2. Outer circumference of plasma surface at midplane = 9m

ELM toroidal coverage at outer midplane = (0.45-0.6)/9 = 5-7%

- TS measurement is made at a specific toroidal location instantaneously
  - → Probability of a specific TS measurement to detect ELM is 5-7%
  - → Ensemble averaged TS Te profile effectively represents inter-ELM profile
- Probe continuously measures IV curves with t_{sweep}=0.25ms and is hit by toroidally rotating ELM filaments, while moving across SOL
  - → Probe Te profile represents an ELM-averaged one (broad profile)
- IR camera measures heat flux profile for 33ms → reflects multiple ELM stripes at the divertor target (broader profile than without ELMs)

[1]R. Maingi, et al., Phys. Plasmas 13, 092510 (2006)

TS measurement for ELM-free H-mode provides evidence of the role of ELM filaments in determining λ_{Te}/λ_q ratio



1. $\lambda_{Te}/\lambda_q = \dfrac{7}{2}\left(\dfrac{T_e - T_{e1}}{T_e - Cq_1 T_e^{-5/2}}\right)$[1]

   is expected if e-conduction is dominant, in light of flat T_e and heat flux profiles in the far SOL (*i.e.*, $\lambda_{Te}/\lambda_q \sim 2$)

2. Experimental results:
   - Type-V ELM H-mode: $\lambda_{Te}/\lambda_q \sim 2$ (Probe *vs* IR)
   - Type-V ELM H-mode: $\lambda_{Te}/\lambda_q \sim 1$ (TS *vs* IR)
   - ELM-free H-mode: $\lambda_{Te}/\lambda_q \sim 2$ (TS *vs* IR)

More evidence is to be investigated in the next campaign:

- Take probe measurement for ELM-free H-mode and compare with IR
- Take fast (~20kHz) IR camera measurement to avoid effect of ELM stripes

[1]J-W. Ahn, submitted to Phys. Plasmas (2008)

Summary and conclusions

1. Dependences of λ_{Te}, λ_{ne}, λ_q, and λ_{jsat} on I_p, nebar, and input power in H-mode plasmas were identified
   - negative dependence on I_p and power
   - no dependence on nebar
   - λ_q change appears to be driven primarily by λ_{Te} change
2. λ_{ne} remains largely unchanged by any parameter scan, due to the stiff edge density gradient in H-mode
3. Comparison with H-mode scaling laws from conventional tokamaks
   - λ_{Te} , λ_{ne} , and λ_q dependence on I_p and power is consistent with scaling laws
   - λ_q dependence on density also consistent with the scaling law
   - λ_{Te} and λ_{ne} dependence on density shows different trend
4. ELM filaments appear to broaden Te and heat flux SOL widths
   - Probe and ensembled TS measurements represent different aspect of type-V ELMy H-mode profiles, *i.e.* ELM-averaged and inter-ELM profiles, respectively

Future Work

1. More data points and confidence
   - SOL width scaling laws for λ_q, λ_{Te} and λ_{ne}
   - Comparison with theoretical models
     eg, SOLPS results and analytic λ_q models
   - Extrapolation to future machines
2. More detailed investigation of parallel SOL transport
   - Roles of parallel convection to account for remaining discrepancy in Near SOL, using the Mach probe in 2009
   - Probe measurement in ELM-free H-mode to double-check the role of e-conduction in parallel transport
3. Fast IR camera measurement to separate ELM effects
4. Investigate relation of SOL widths with edge turbulence characteristics, eg, Probe I_{sat} data, GPI data, Edge reflectometry data
   - Investigation of perpendicular SOL transport

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