SCALING OF DIVERTOR HEAT FLUX PROFILE WIDTHS IN DIII-D

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Peak steady-state divertor heat flux, q_{div} , in high confinement burning plasmas remains an open design issue for next generation high power tokamaks such as ITER, largely because of uncertainties in the heat flux profile width, λ_q. Recent experiments in DIII-D featuring divertor heat flux measurements with improved temporal and spatial resolution show that the divertor heat flux profile width in ELMing H-mode single-null discharges, $\lambda_{q,div}$, varies as $1/I_p^{1.2}$ and is nearly independent of power, in agreement with earlier data [C.J. Lasnier, et al., Nucl. Fusion **38**, (1998) 1225]. The divertor heat flux was calculated from infrared camera measurements using a new high-resolution fast-framing IR camera (107 μs frame time and 2.5 mm spatial resolution). The frame rate was sufficiently fast to resolve the quiescent heat flux from that due to ELMs. Scans of plasma current and magnetic field were also obtained at constant edge safety factor, q_{95}, to avoid changing the SOL connection length. Preliminary analysis of these data shows the width decreasing linearly with $|B_T|$, presumably due to the changing plasma current and transport. The relation between the divertor heat flux profile width and the midplane SOL plasma parameters is needed for SOL model validation activities and to heat flux scaling studies for tokamak design; SOL models predict $\lambda_{T_e} = (7/2)\,\lambda_q$. However, our data show that $\lambda_{T_e} \approx$ const even as $\lambda_{q,div}$ varies by nearly a factor of two. We are comparing our results to simulations from the UEDGE 2D fluid code, which accurately includes the SOL magnetic geometry, divertor geometry and neutral recycling, and radiative losses. In these simulations we are focusing on testing the physics by matching the observed trends rather than detailed profiles since the number of free parameters controlling the divertor/SOL conditions greatly exceeds the number of measurements.
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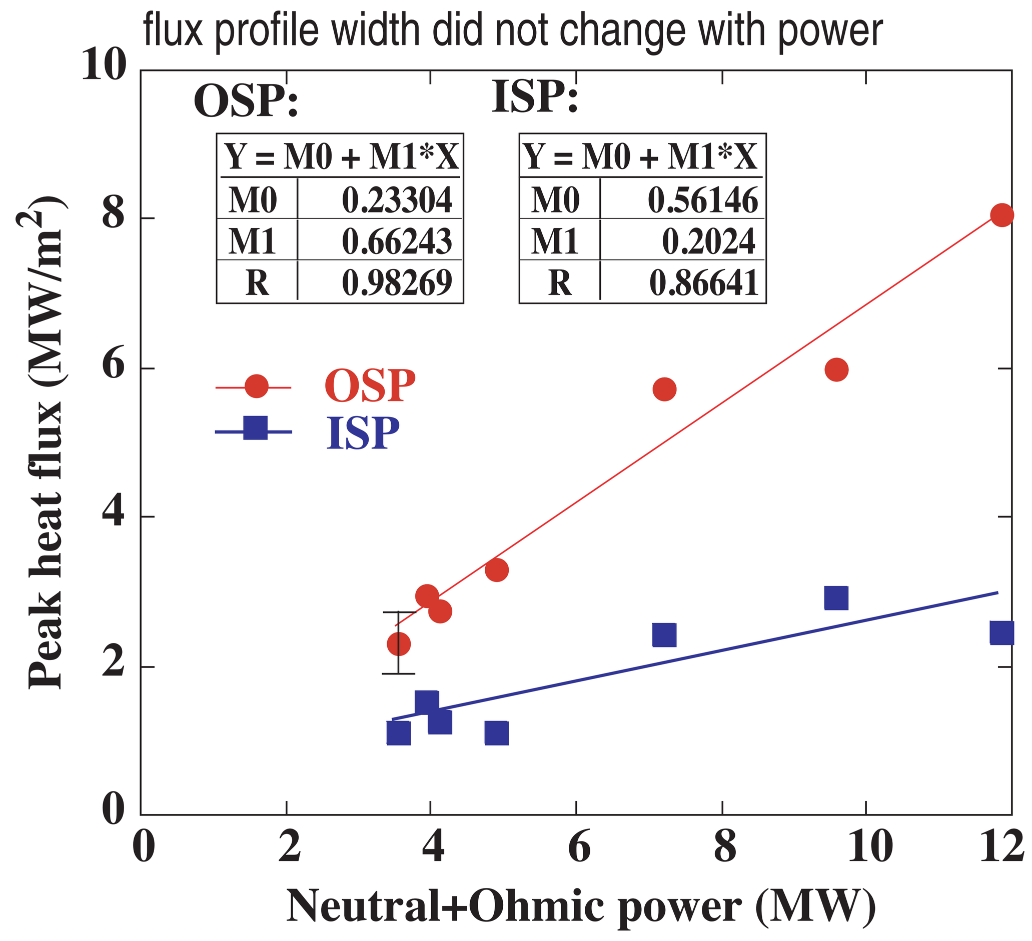
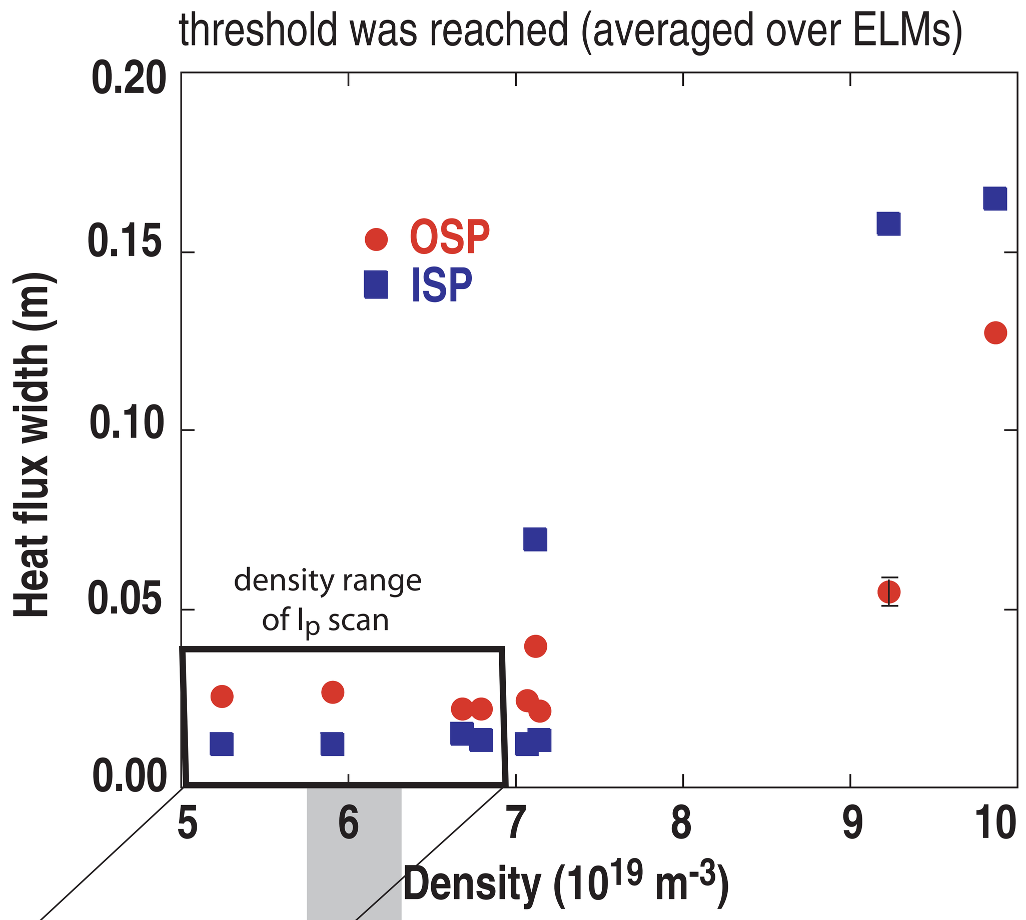
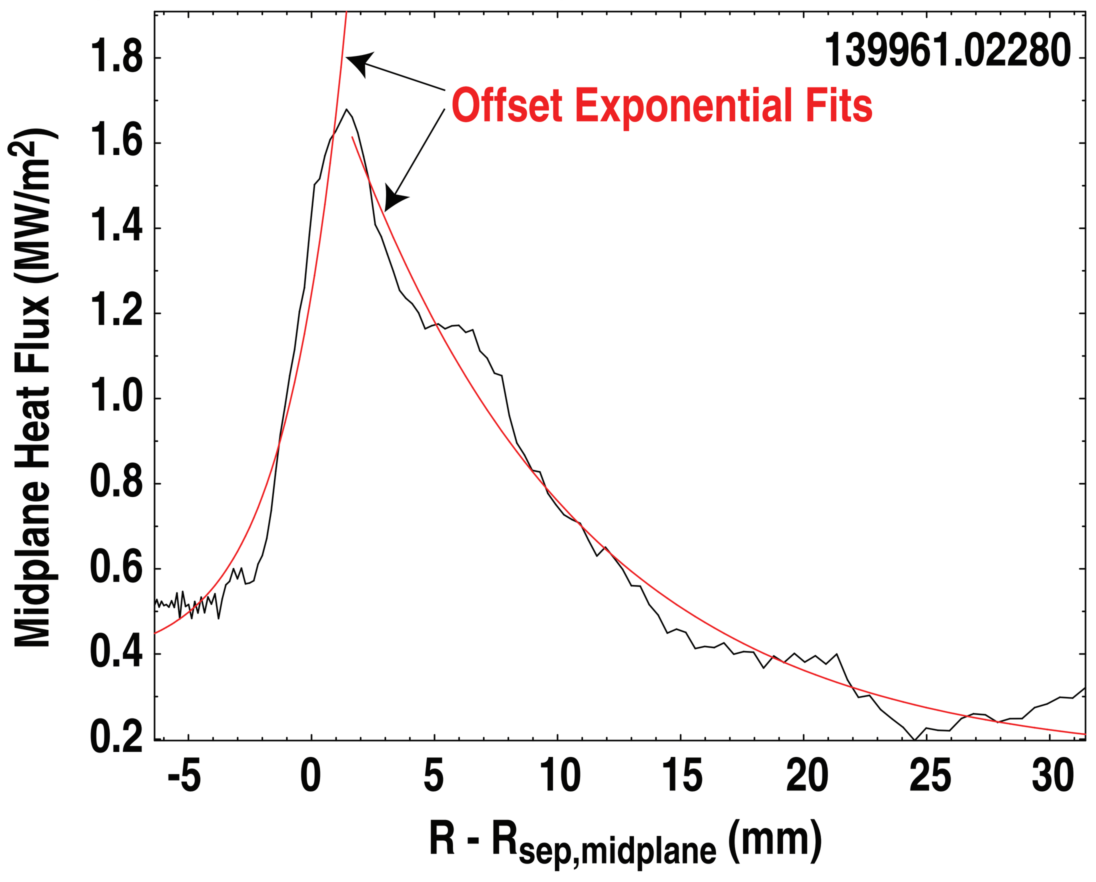
The peak heat flux in the divertor increased linearly with total heating power (averaged over ELMs). Heat flux profile width did not change with power



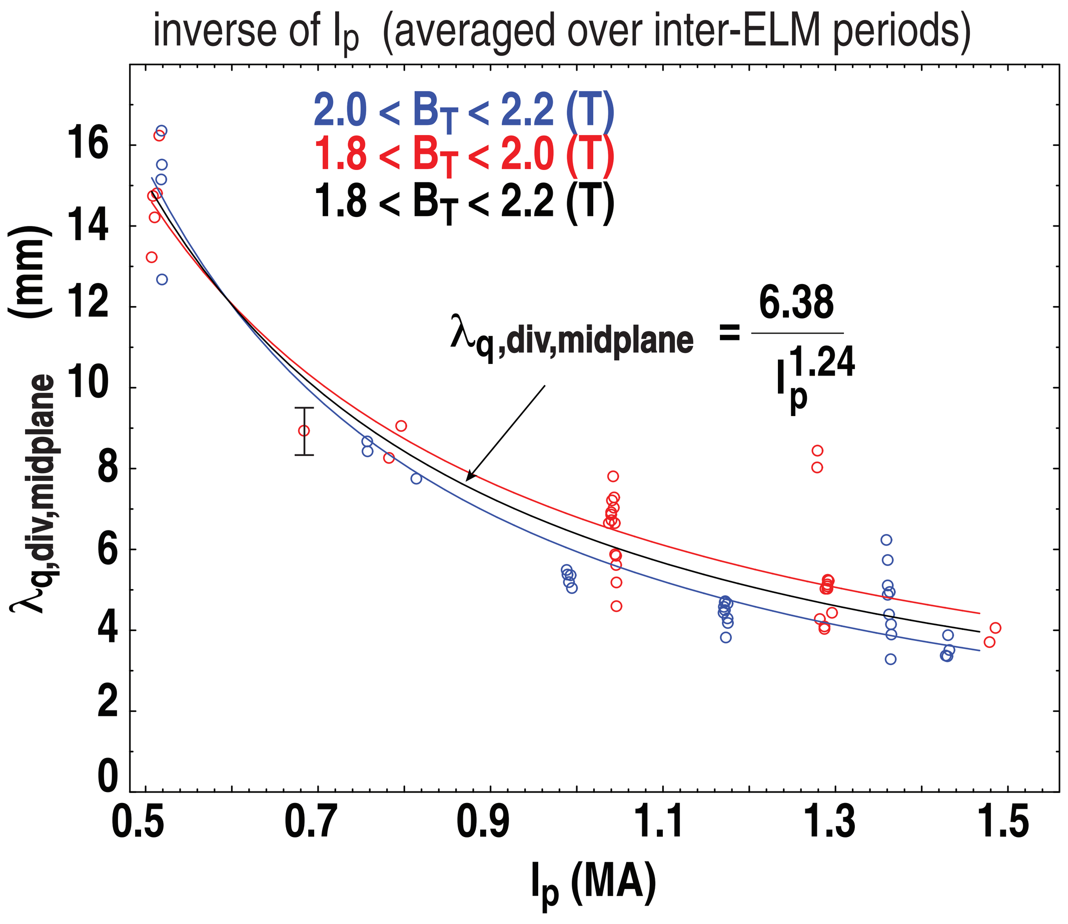
The full width at half-maximum heat flux in the divertor did not change with density until the detachment threshold was reached (averaged over ELMs)



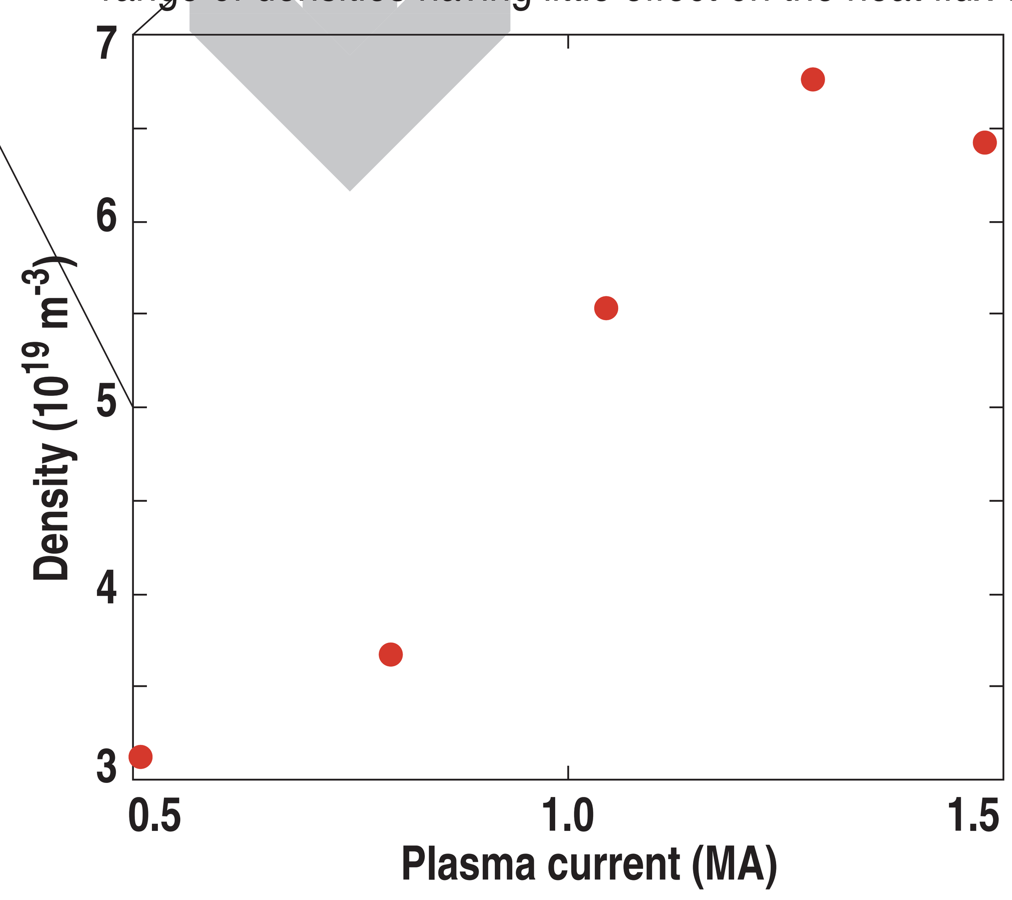
Divertor heat flux was mapped to the outer midplane and the profile was fit with offset exponentials



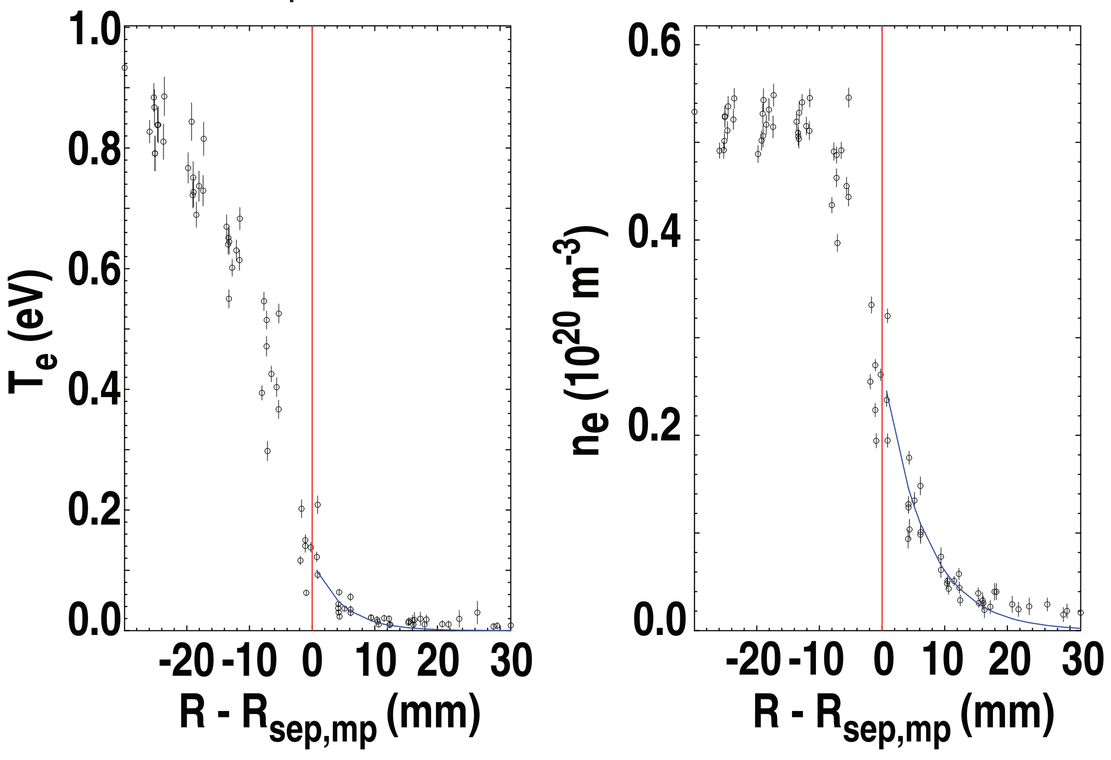
Fitted exponential width of the divertor heat flux profile mapped to the outer midplane, varied nearly as the inverse of I_p (averaged over inter-ELM periods)



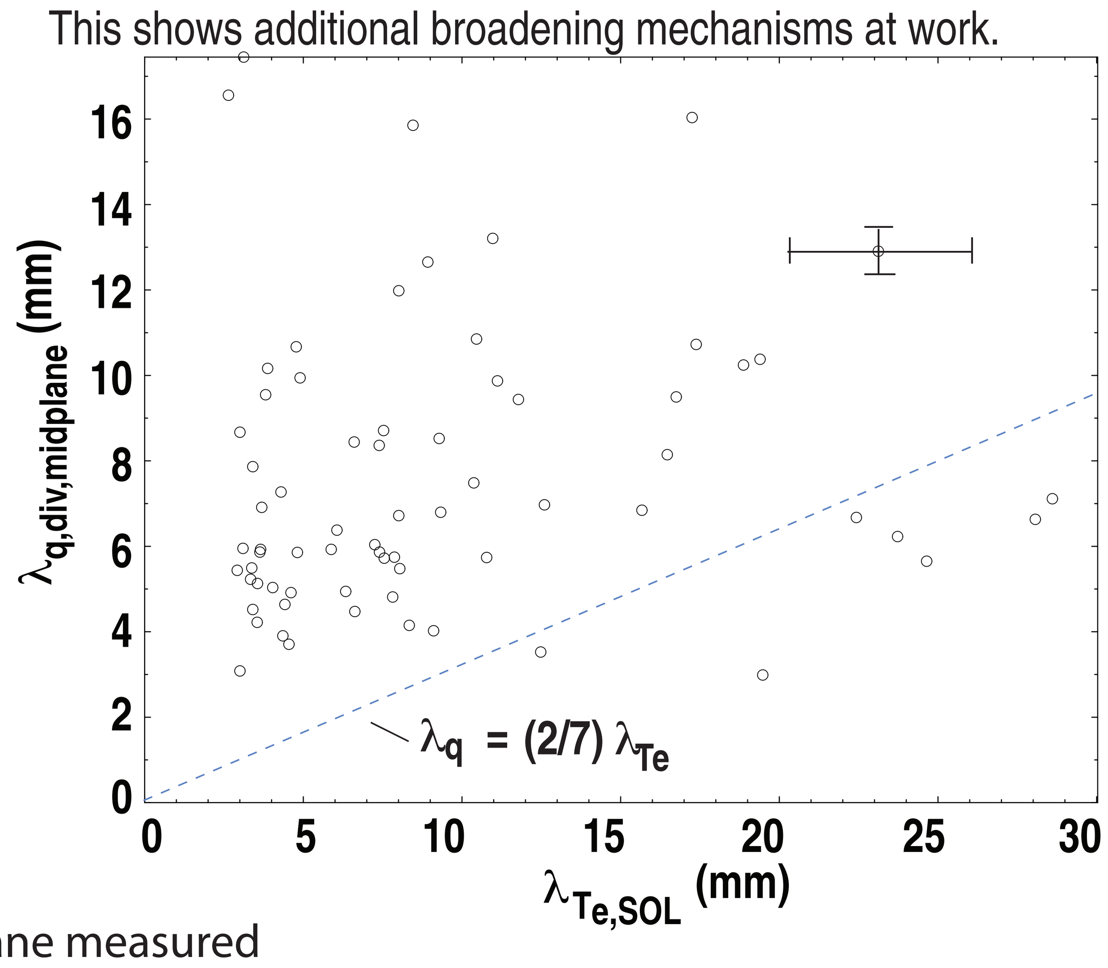
Density variation during the I_p scan was within the range of densities having little effect on the heat flux width



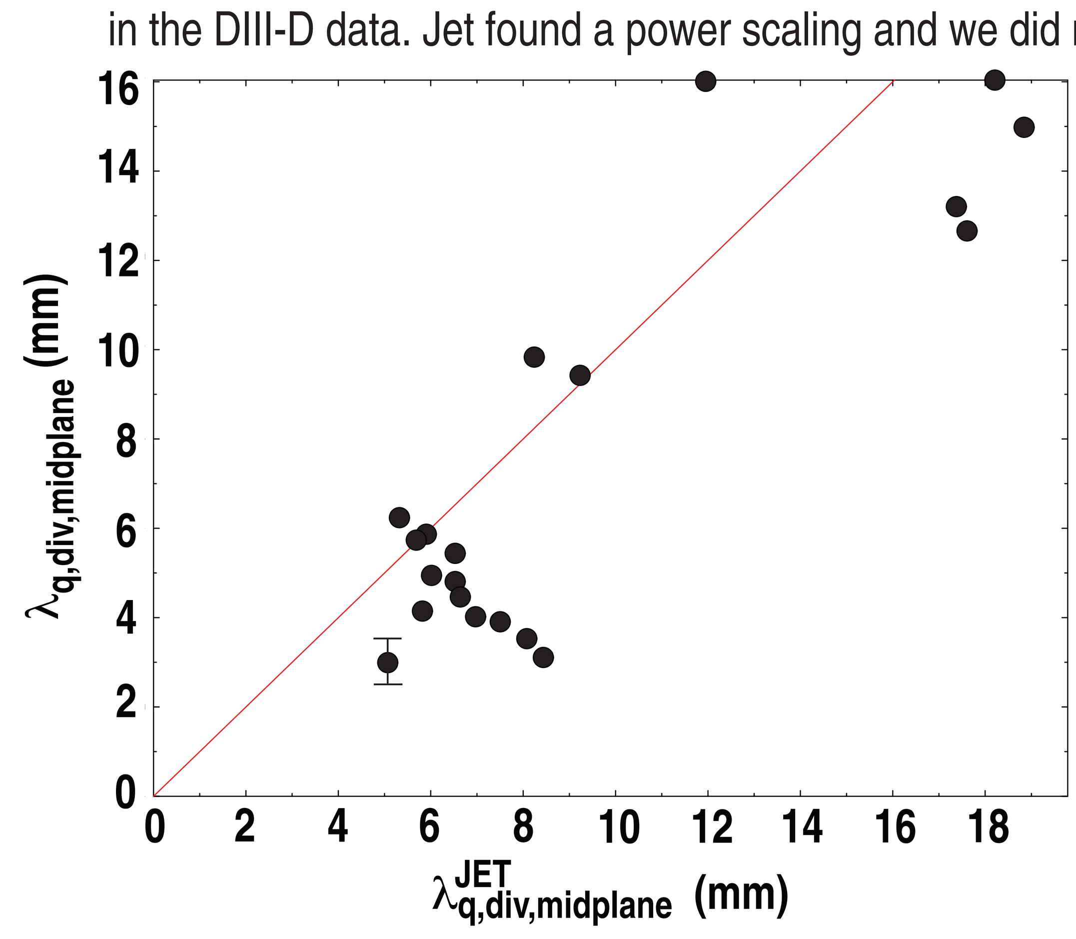
Electron temperature and density profiles were obtained from Thomson scattering measurements, mapped along flux surfaces to the outer midplane, and the SOL side was fitted to exponential functions



Comparison of inter-ELM divertor heat flux mapped to the outer midplane with Thomson scattering electron temperature profile widths shows the heat flux is wider than predicted by a two-point model (dashes)
[PITCHER, C.S. AND STANGEBY, P.C., Plasma Phys. Control. Fusion **39** (1997) 779].
This shows additional broadening mechanisms at work.



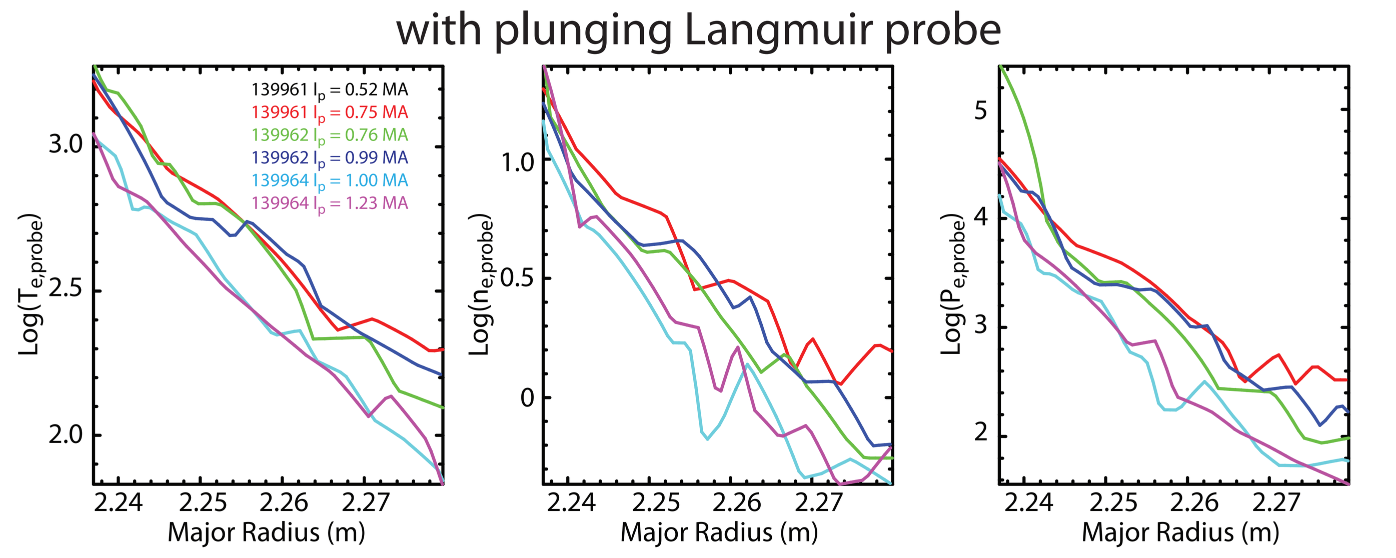
Comparison of DIII-D inter-ELM heat flux widths to a JET scaling shows similar parameter dependence but does not account for all variation. There is no size variation in the DIII-D data. Jet found a power scaling and we did not.



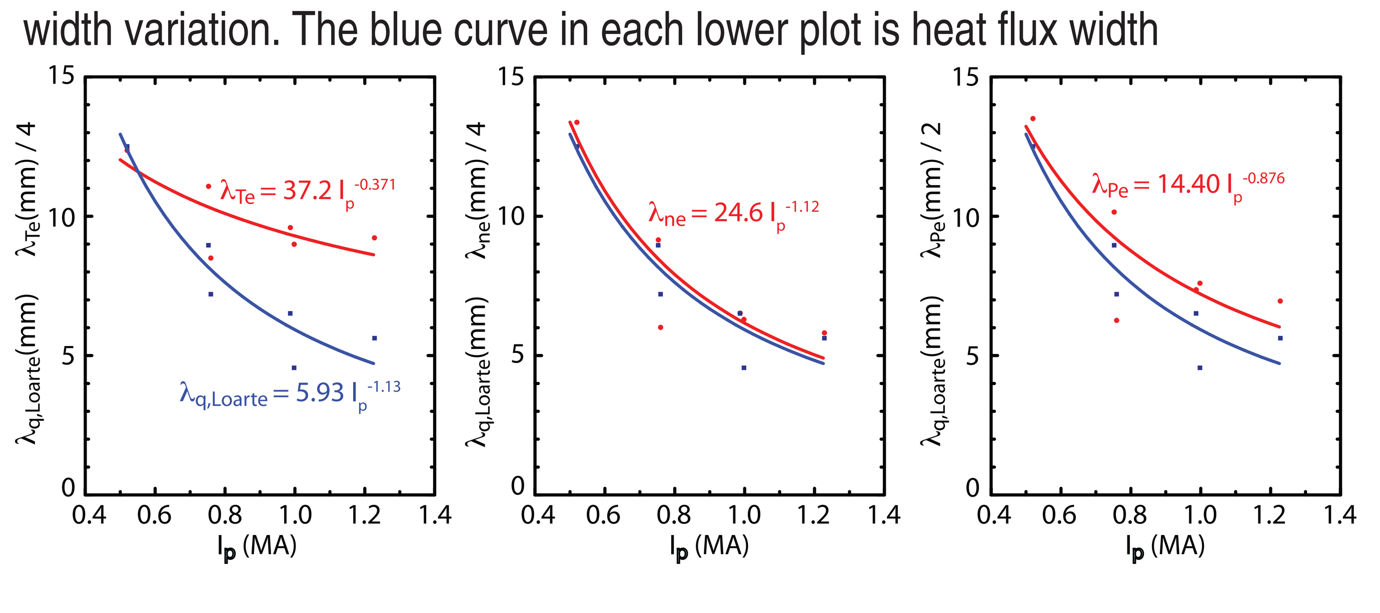
$$\lambda^{JET}_{q,div,midplane}\ (\mathrm{mm}) = 2.41\times10^{-5}\, B_T^{-1}(\mathrm{T})\, P_{SOL}^{-1/2}\ (\mathrm{MW})\, n_e^{1/4}\left(\mathrm{m}^{-3}\right) q_{95} R^2\ (\mathrm{m})$$

[KIRNEV, G., *et al.*, Plasma Phys. Control. Fusion **49** (2007) 689]

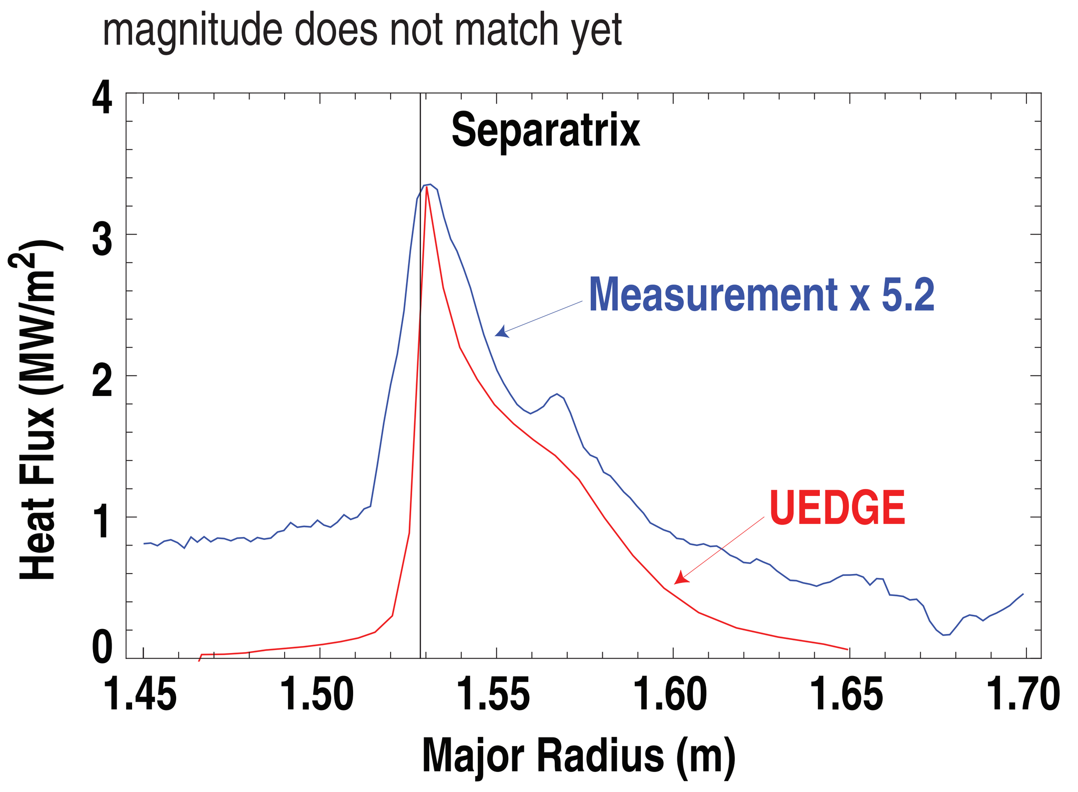
T_e, n_e, and p_e (electron pressure) profiles at outer midplane measured with plunging Langmuir probe



T_e gradient scale length scales differently with I_p than the divertor heat flux width. The n_e gradient scale length and divertor heat flux width scale similarly with I_p. The p_e gradient scale length variation is close to that of the heat flux width variation. The blue curve in each lower plot is heat flux width



Preliminary UEDGE modeling shows inclusion of drifts is important in matching heat flux widths. The heat flux magnitude does not match yet



Conclusions

- The strongest dependence we see is the heat flux width scales like $1/I_p^{1.2}$.
- The heat flux profile is wider than predicted from a two-point model, indicating additional broadening mechanisms such as radiation and neutral transport.
- Qualitative agreement with dependences of the Kirnev JET scaling, but size scaling was not yet checked.
- UEDGE modeling of these discharges has begun.