SOL Width Studies for ITER Ramp-up/Down

by
D.L. Rudakov,[1]

with
J.A. Boedo,[1] R.A. Moyer[1]
R.A. Pitts,[2] A.W. Leonard,[3] G.L. Jackson,[3]
C.J. Lasnier,[4] P.C. Stangeby,[5]
J.G. Watkins,[6] L. Zeng,[7]

[1]University of California, San Diego
[2]ITER Organization
[3]General Atomics
[4]Lawrence Livermore National Laboratory
[5]University of Toronto Institute for Aerospace Studies
[7]University of California, Los Angeles

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Motivation

- The present ITER scenarios foresee initial and final ramp-up/down limiter phases in Ohmic or L-mode with very low additional heating
- Power flux e-folding length is a crucial design parameter for the limiters
- For the diverted L-mode phase a scaling law derived from divertor power flux measurements on JT-60U, JET, and ASDEX-Upgrade is assumed *(with an uncertainty of a factor of ~ 2 around this value):*

$$\lambda_p\ (\mathrm{m}) = (1\pm1/3)\ 3.6\ 10^{-4}\ R(\mathrm{m})^2\ P_{div}(\mathrm{MW})^{-0.8} \times q_{95}^{0.5} \times n_e(10^{19}\mathrm{m}^{-3})^{0.9} \times Z_{eff}^{0.6}$$

- The same L-mode scaling has been applied to the limiter phases by:
  - replacing the power to the divertor by the power to the limiters
  - taking into account number and spatial location of the limiters (HFS vs LFS)
- ITER STAC-5 report: The local λ_p at the limiter PFCs is expected to be ~4 times larger if the plasma is limited at the HFS than at the LFS (mostly due to the strong ballooning component of the edge transport)
- Of this factor, ~1.6 is due to the flux expansion at HFS; if λ_p is measured at the LFS, HFS- and LFS-limited cases should differ by a factor of ~ 2.5

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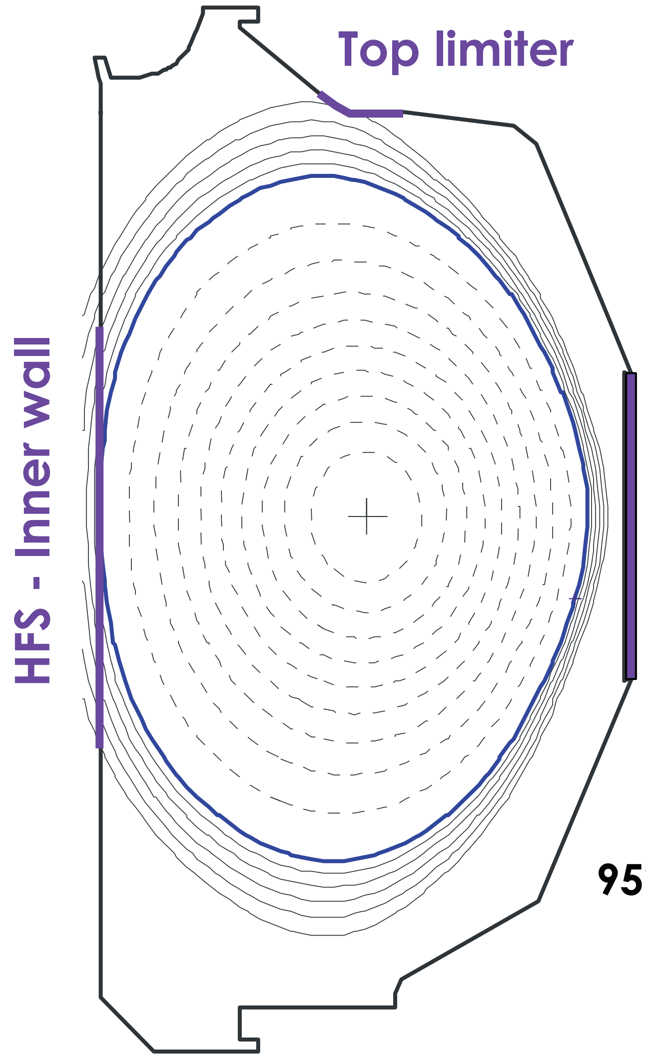
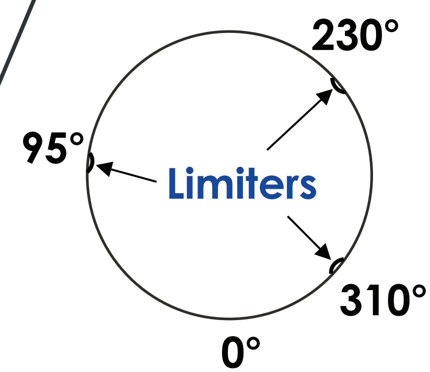
Limiter Options in DIII-D



LFS Limiters
(3 off)



- Inner wall and top “knee” limiter are toroidally symmetric
- LFS limiters are localized and have small poloidal extent

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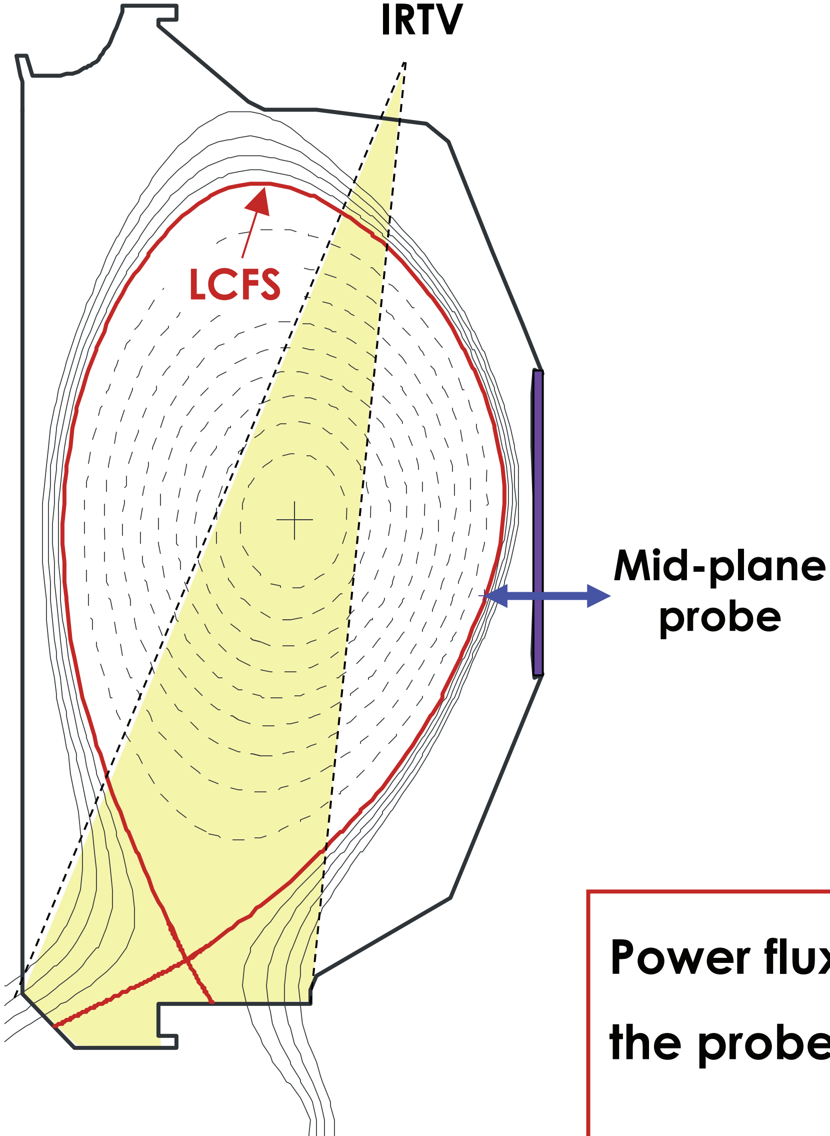
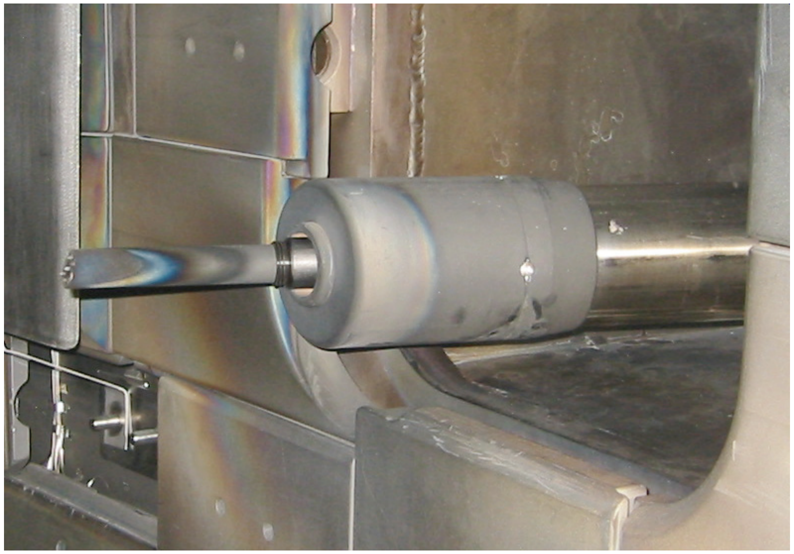
Diagnostic Arrangement



Mid-plane reciprocating probe array



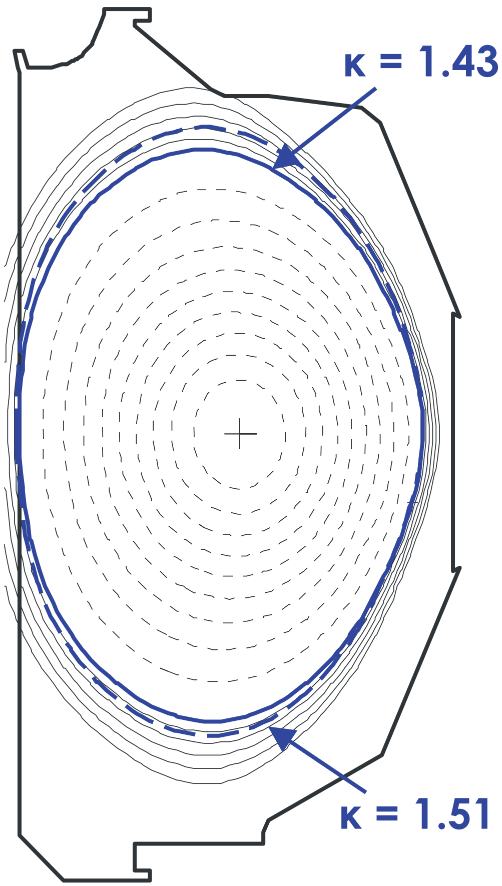
- **5-pin array**
- **Measured parameters:** I_{si} T_e V_f
- **Derived parameters:** n_e V_p E_θ $\Gamma_\perp$ $Q_\perp$

Power flux e-folding length is estimated from the probe data assuming $T_i = T_e \rightarrow$ $Q_{||} \propto n\, T_e^{3/2}$

$$1/\lambda_p = 1/\lambda_n + 3/2\,\lambda_T$$

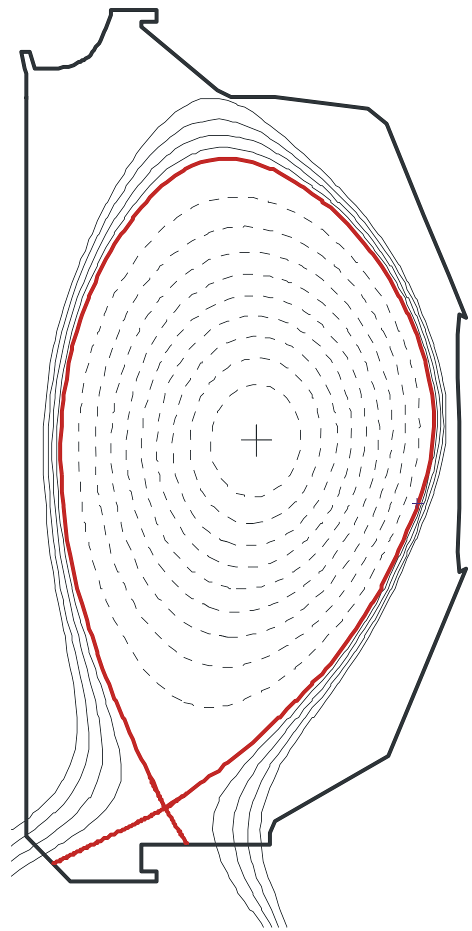
Limited and Diverted Plasma Shapes Studied

HFS-limited ≡ IWL



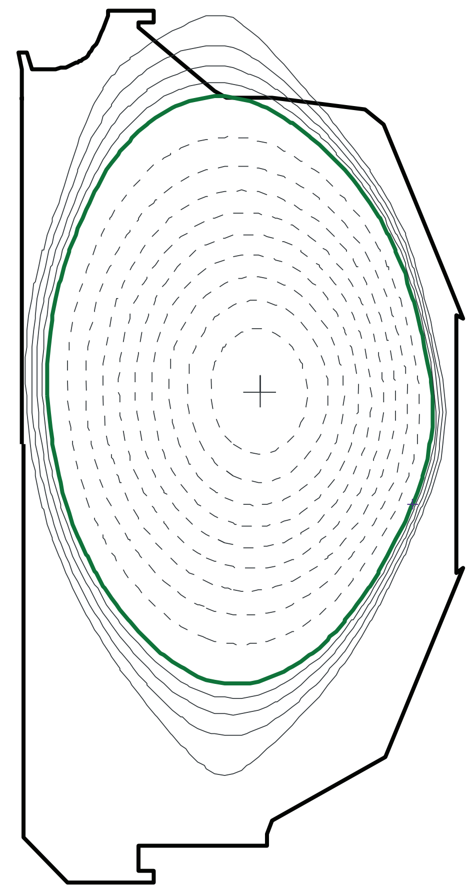
24 discharges, 37 profiles

Lower Single Null ≡ LSN



10 discharges,10 profiles

Top-limited ≡ TL



1 discharge, 2 profiles

We did not run LFS-limited shape because LFS-limited SOL lacks toroidal symmetry

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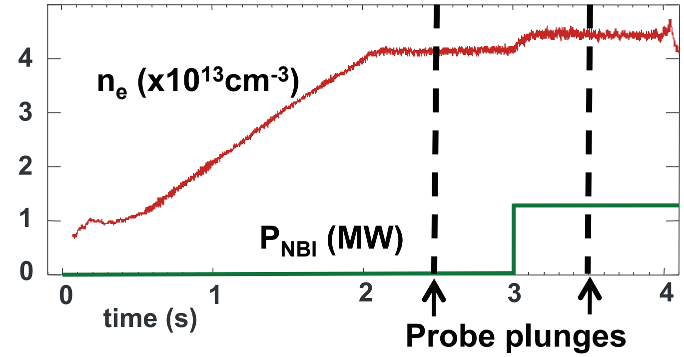
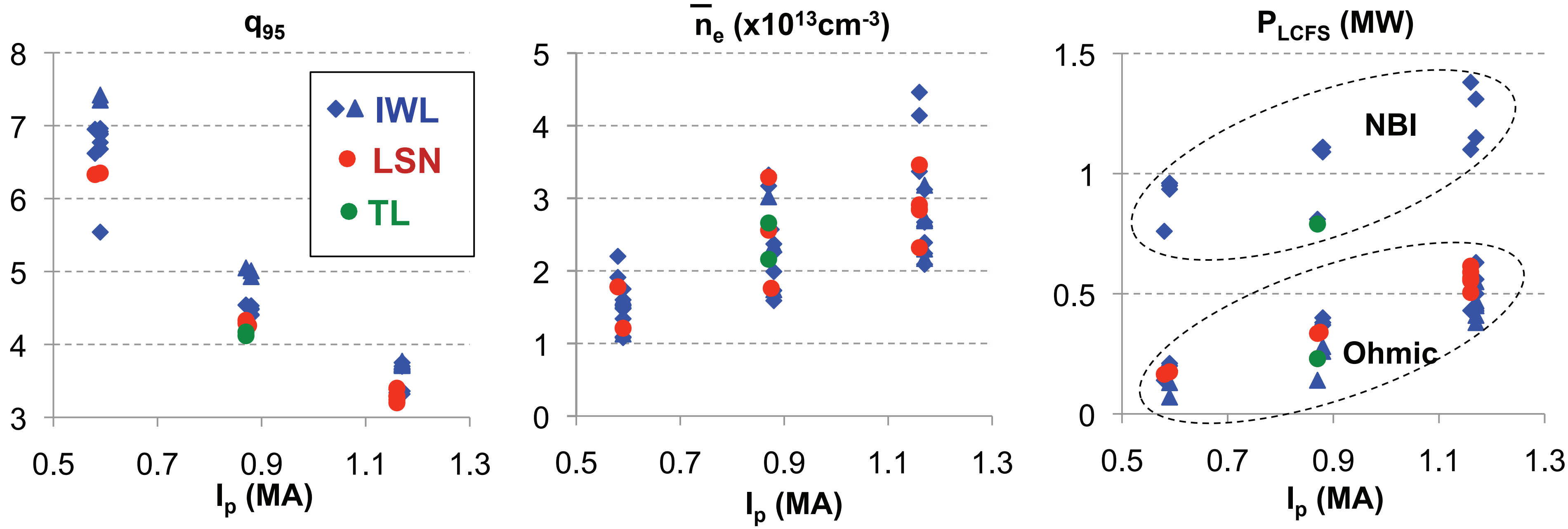
Parameter Space Covered

- IWL: n_e scans performed at three I_p levels and two P_{NBI} levels (0 and 1.25 MW)
- LSN: n_e performed at three I_p levels
- SOL profiles taken during stationary phases





Parameter ranges: q_{95} = 3.2 – 7.4 → x2.3 variation

n_e = 1.1 – 4.5x10^{13}cm^{-3} → x4 variation

$P_{LCFS} = P_{Ohmic} + P_{NBI} - P_{rad\_core}$ = 0.1 – 1.4 MW → x14 variation

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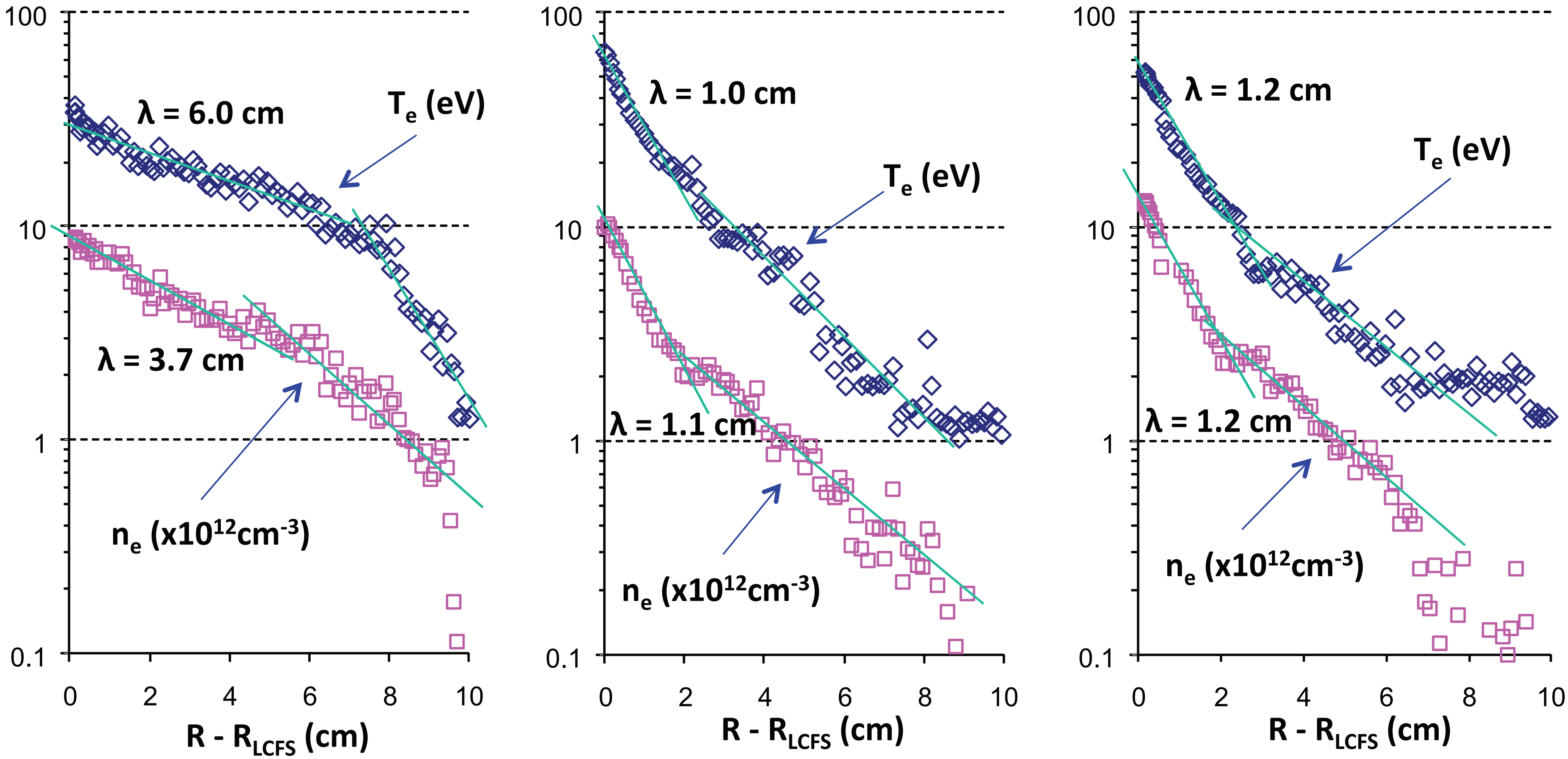
SOL n_e and T_e e-folding Lengths Obtained from Probe



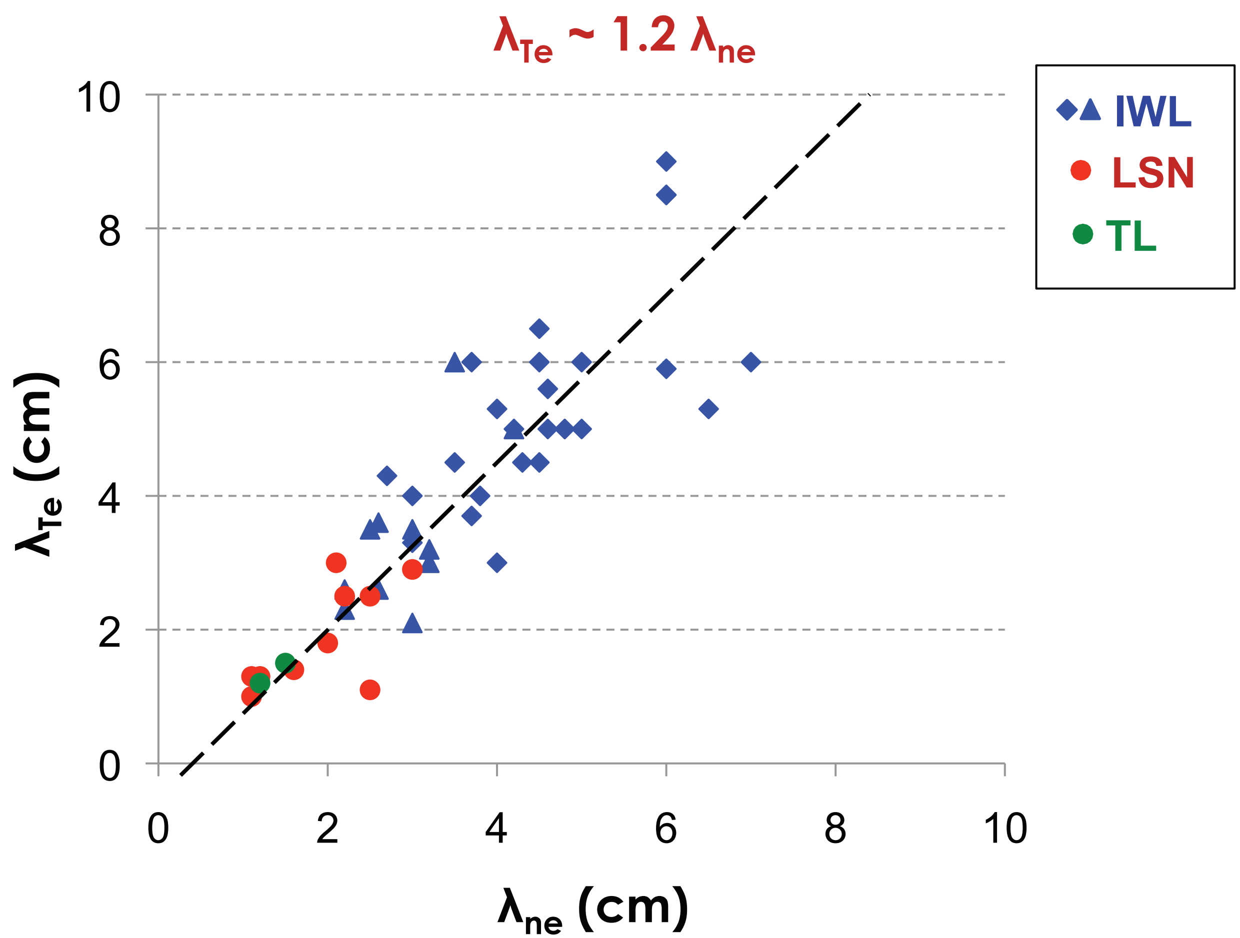
IWL
I_p = 0.88 MA
$n_e = 2.37\times10^{13}cm^{-3}$
P_{LCFS} = 0.4 MW

LSN
I_p = 0.88 MA
$n_e = 1.76\times10^{13}cm^{-3}$
P_{LCFS} = 0.23 MW

TL
I_p = 0.87 MA
$n_e = 2.16\times10^{13}cm^{-3}$
P_{LCFS} = 0.23 MW

Near-LCFS e-folding lengths are of interest for the scaling

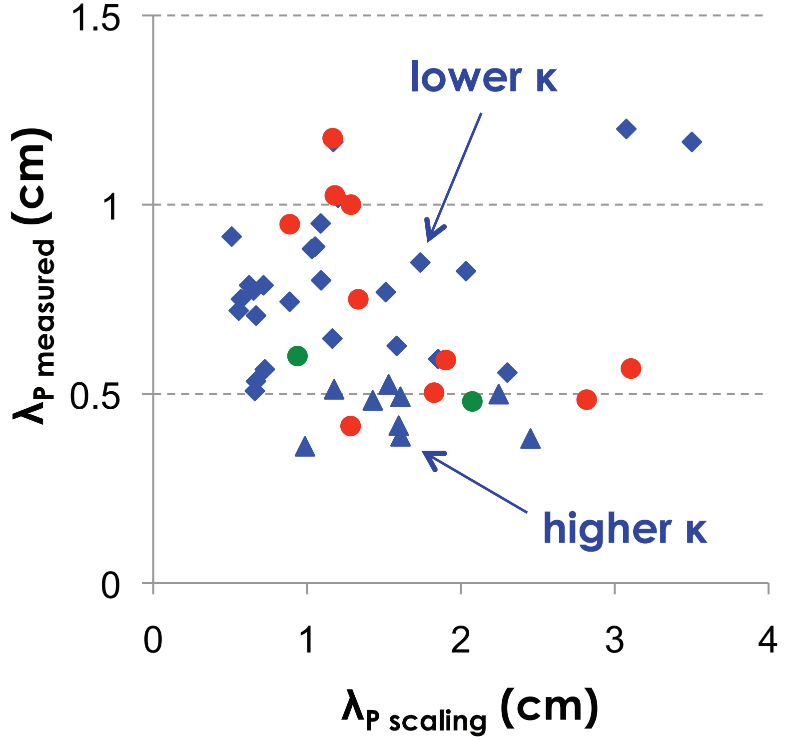
SOL n_e and T_e e-folding Lengths are Correlated

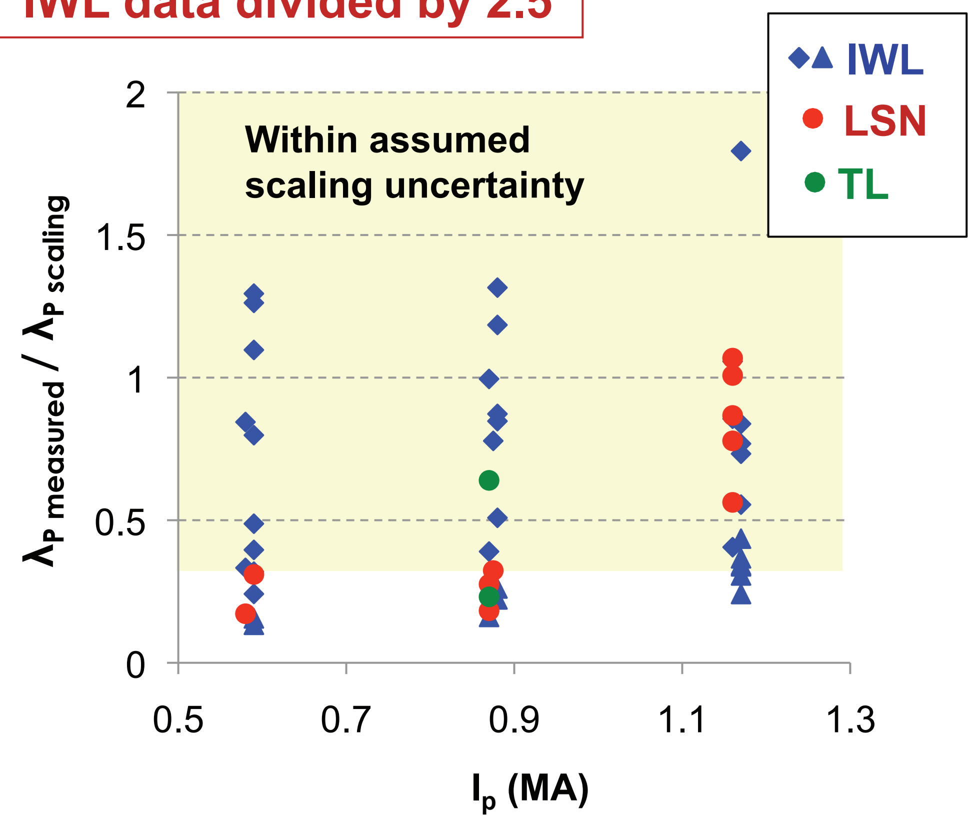


- SOL width in IWL is larger than in LSN and TL
- The expected difference per ITER STAC report should be ~ x2.5
- Our results are roughly consistent with the ITER expectations

Comparison of λ_p with ITER Scaling

$1/\lambda_p = 1/\lambda_{ne} + 3/2\,\lambda_{Te}$ IWL data divided by 2.5





- Most of IWL data within the assumed uncertainty of the ITER scaling
- At the highest I_p (lowest q_{95}) the agreement is the best
- There is a tendency of the measured λ_p to be lower than predicted by the scaling, particularly in LSN and higher elongation IWL

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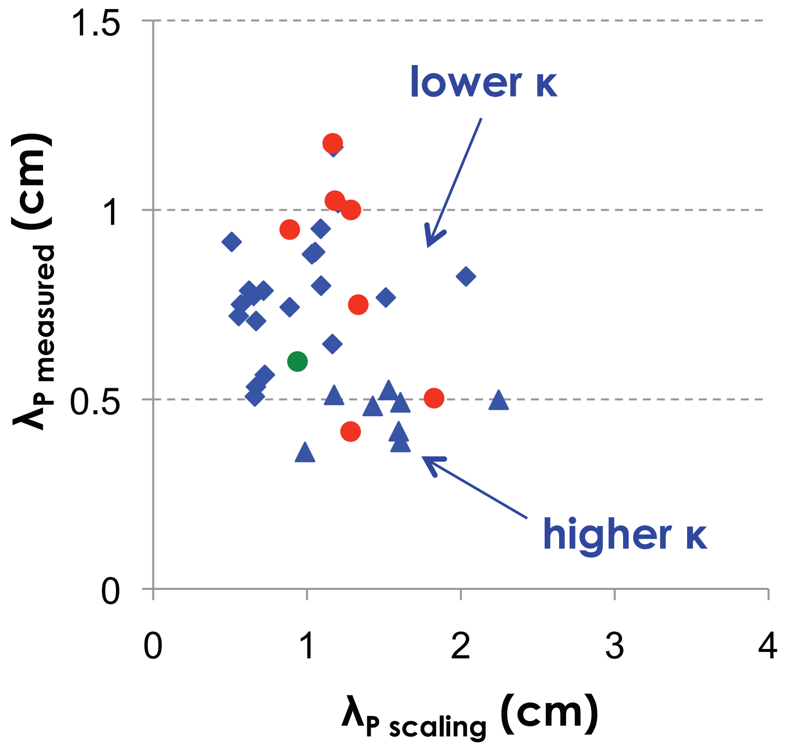
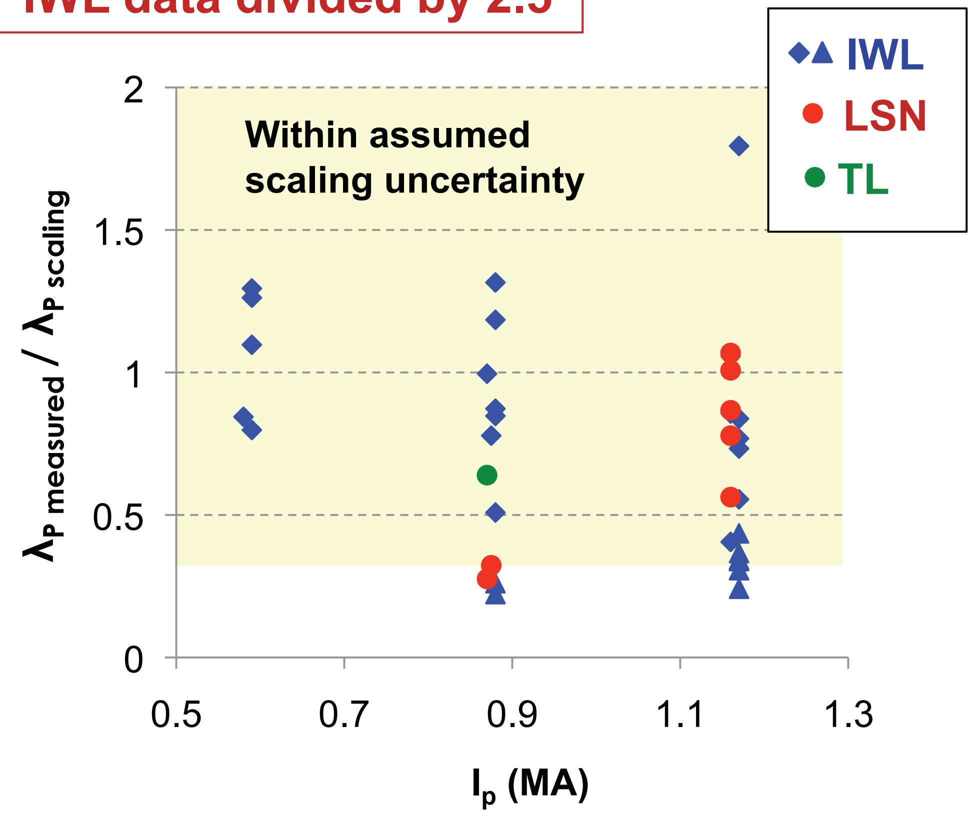
Same with Radiation-Dominated Discharges Removed

$1/\lambda_p = 1/\lambda_{ne} + 3/2\,\lambda_{Te}$ IWL data divided by 2.5

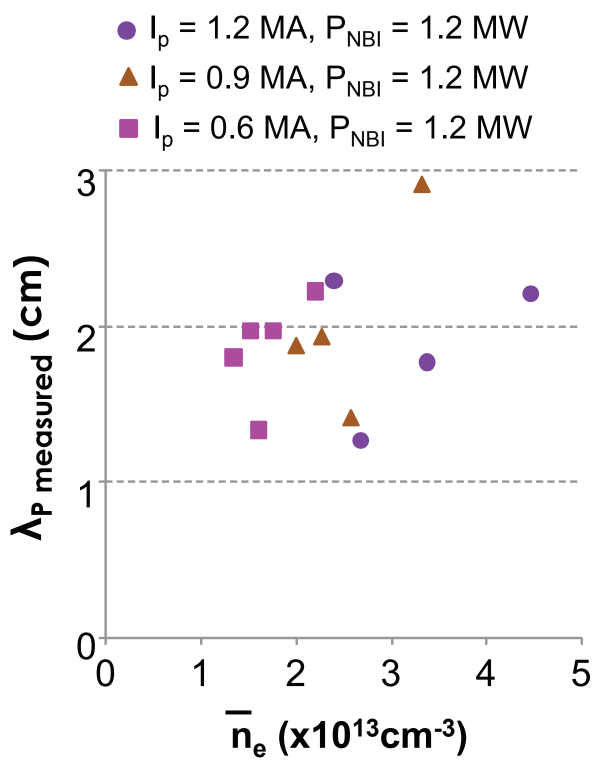


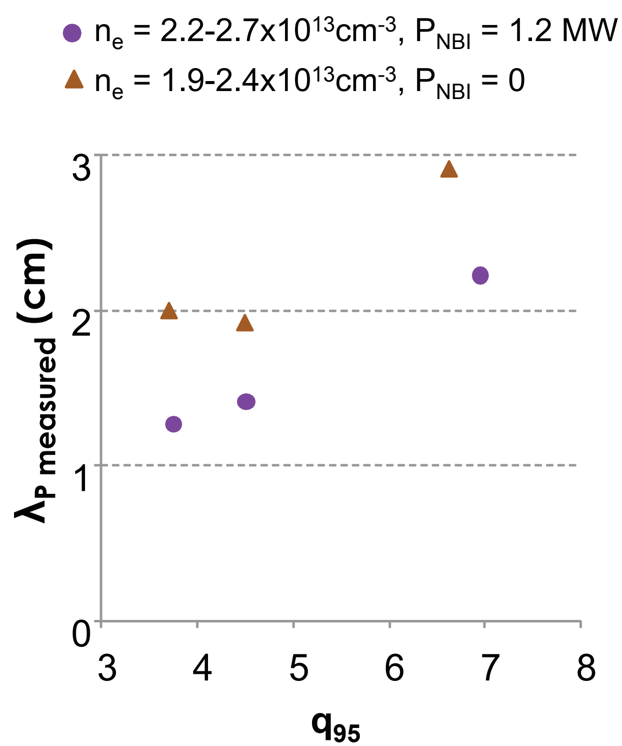


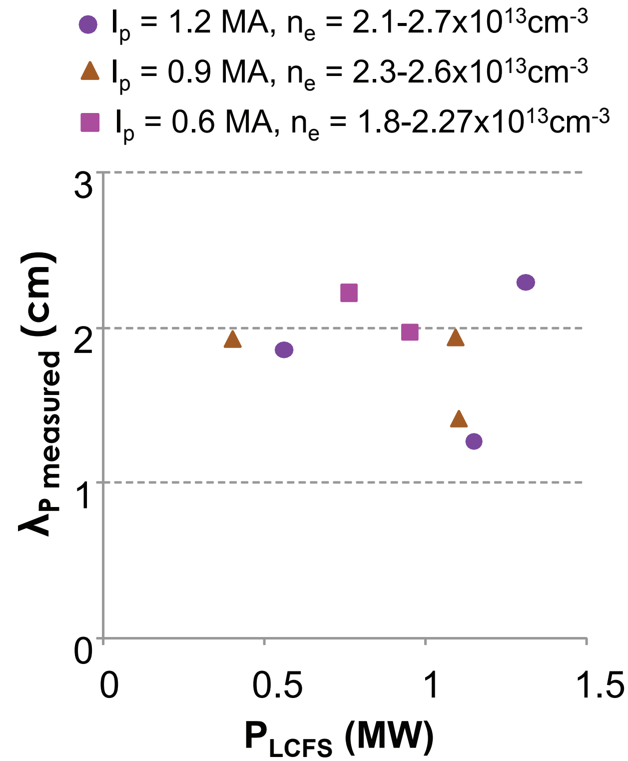
- Radiation-dominated discharges (with P_{LCFS} < 0.25 MW) are removed
- This improves agreement with the scaling (except in lower-κ IWL)
- All remaining lower-κ IWL points are within the scaling uncertainty
- The points are scattered so $\lambda_{p\ measured} \not\propto \lambda_{p\ scaling}$

No Clear Dependencies of λ_P on n_e q_{95} P_{LCFS}

All data from lower-κ IWL







Scaling: $\lambda_p \propto n_e^{0.9}$ **Scaling: $\lambda_p \propto q_{95}^{0.5}$** **Scaling: $\lambda_p \propto P^{-0.8}$**

- **Experiment shows some tendency for λ_p to increase with n_e and q_{95}**
- **No clear trend with power**
- **Shot-to-shot variation and interdependence of parameters make it hard to determine λ_p dependencies on the individual parameters**

Summary

- We have benchmarked ITER SOL power flux width scaling in limited and diverted configurations in DIII-D
- In low-elongation Inner-Wall-Limited (IWL) configuration, our data agree with the scaling within the assumed uncertainties
- In higher elongation IWL and in diverted LSN configurations, the SOL power width in DIII-D tends to be below that given by the scaling
- Dependencies of the SOL power width on the individual discharge parameters could not be confirmed due to shot-to-shot variations and parameter interdependence