SOL width scaling and extrapolation to NHTX

R. Maingi, J-W. Ahn*, J. Boedo*
Oak Ridge National Laboratory
*Univ. California - San Diego

NSTX Boundary Physics ET meeting
Princeton, NJ
Feb. 6, 2007

Need to predict heat flux distributions for NHTX basic design

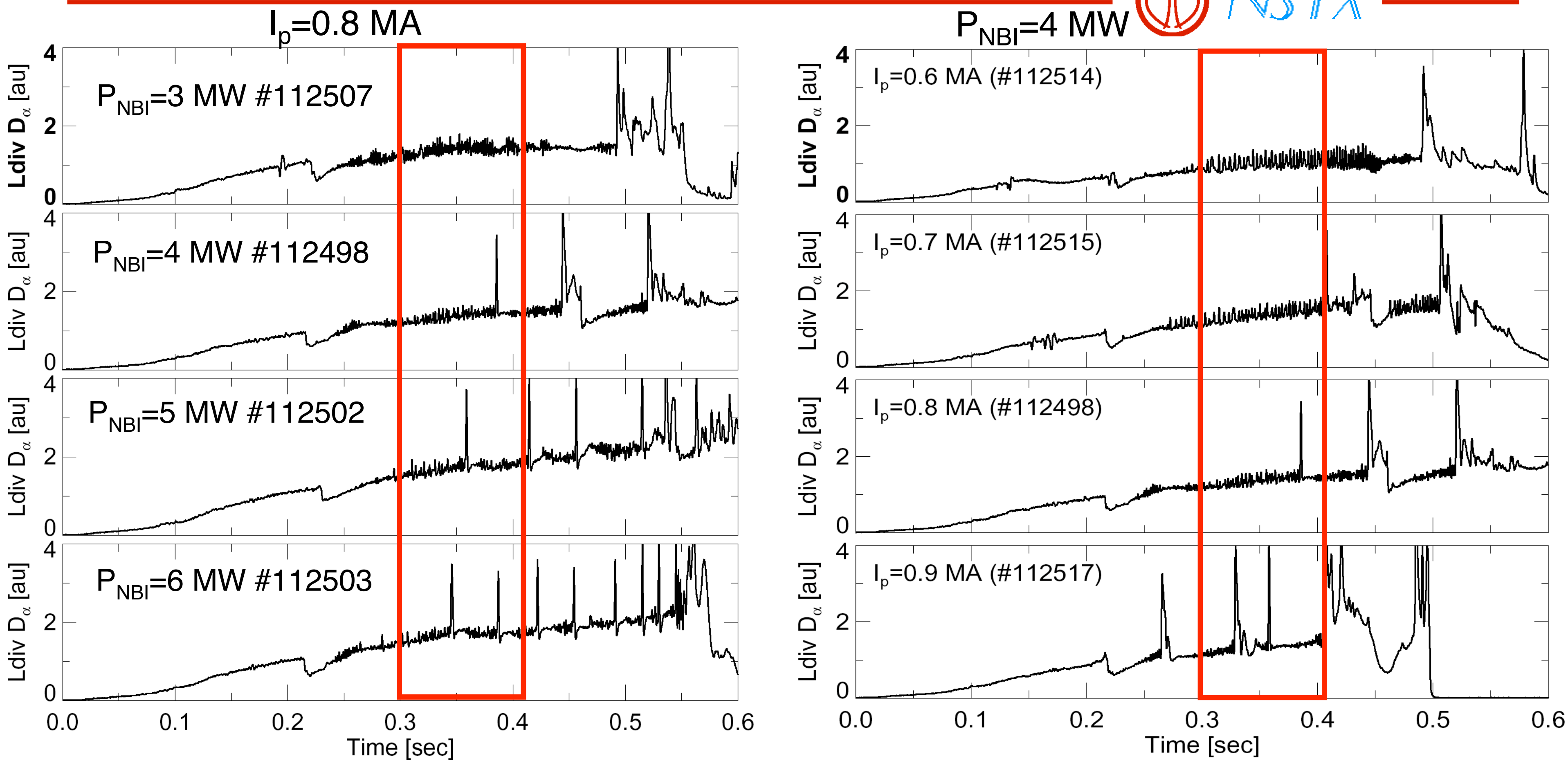
NSTX

- In NSTX, peak heat flux $\geq$ 10 MW/m^2 has been observed
  - Pulse length limit of 2-3 sec for carbon PFCs
- Biggest extrapolations from NSTX to NHTX:
  - P_{heat}: 7-10 MW -> 30-40 MW
  - I_p: 1.0 MA -> 3.5 MA
  - B_t: 0.55 T -> 2.0 T
  - $(R/a)_{min}$: 1.3 -> 1.8
- Would like to use analytic models to extrapolate, but they don't seem to apply (at least quantitatively) to STs
- Propose research program to measure the SOL widths, and compare with existing/new analytic models

Desire measurement of all SOL widths to test models

- Models can predict λ_q, λ_{Te}, λ_n (, λ_Γ , λ_{qe}?)
  - E.g. relation $\lambda_q = (2/7)\,\lambda_{Te}$ in electron conduction limit
- **$\lambda_q^{SOL,mid}$: IR cameras**
  - Requires mapping to midplane
  - Interpretation complicated if in radiative divertor regime
  - Possible quantitative interpretation issues due to surface emissivity variations during run
- **$\lambda_{Te}^{SOL,mid}$, $\lambda_n^{SOL,mid}$, $\lambda_\Gamma^{SOL,mid}$, $\lambda_{qe}^{SOL,mid}$: reciprocating probe**
  - Just below midplane, so mapping less of an issue
  - Limitations on separatrix access at high power
- Very little common data between these diagnostics during parameter scans

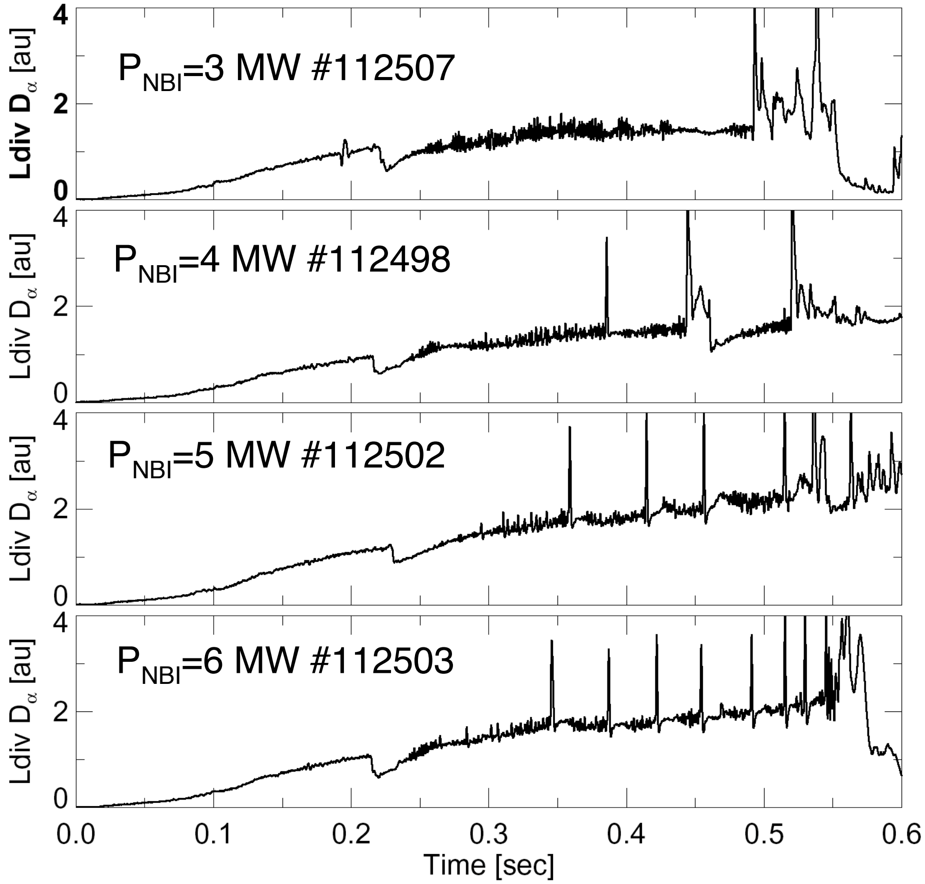
Good P_{NBI} scan and limited I_p scan obtained in 2004 during XP434

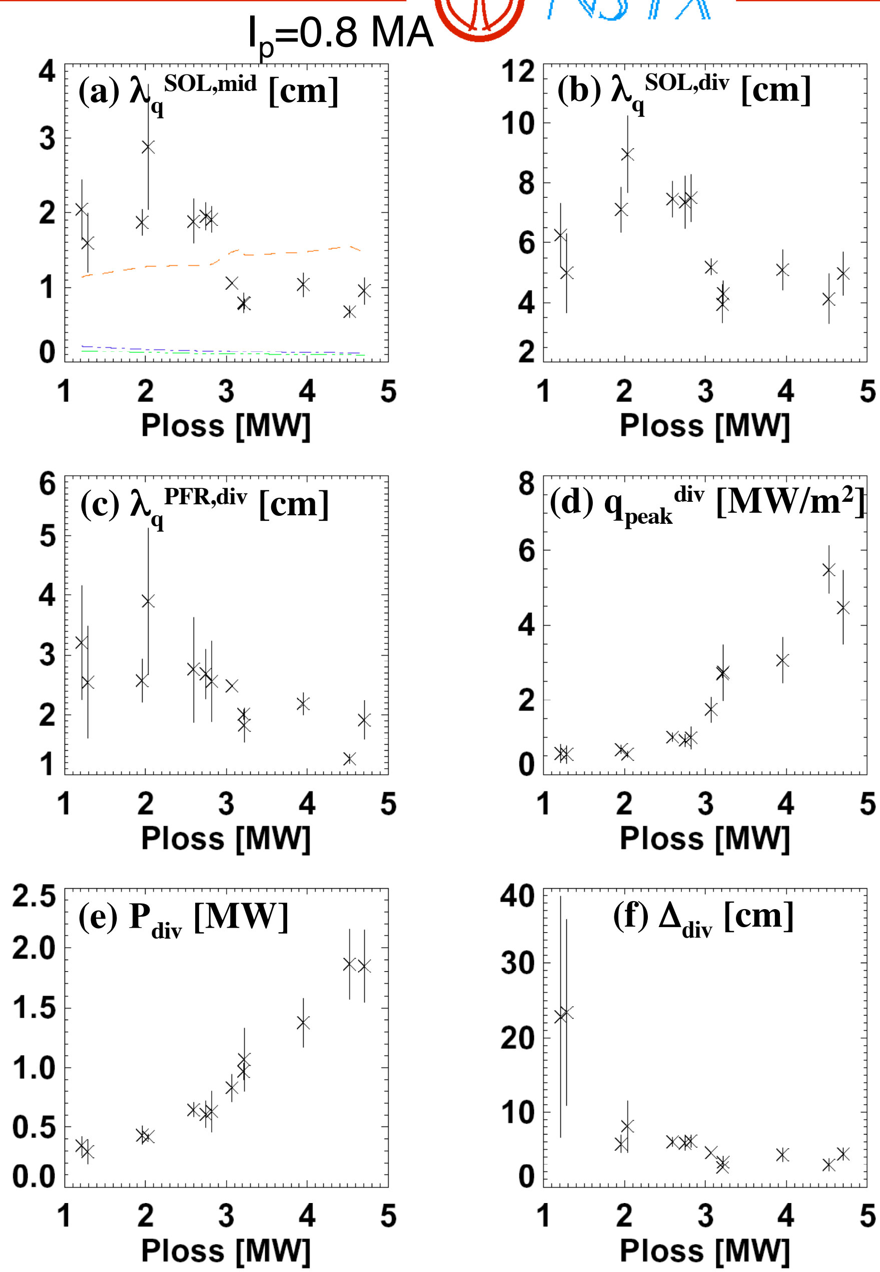


- Time window of interest in red for PSI 2006 paper
- For recent memo, all data before “compound ELM” or mini-disruption utilized

SOL power flux width and peak heat flux make transition at P_{loss} ~ 3 MW

NSTX

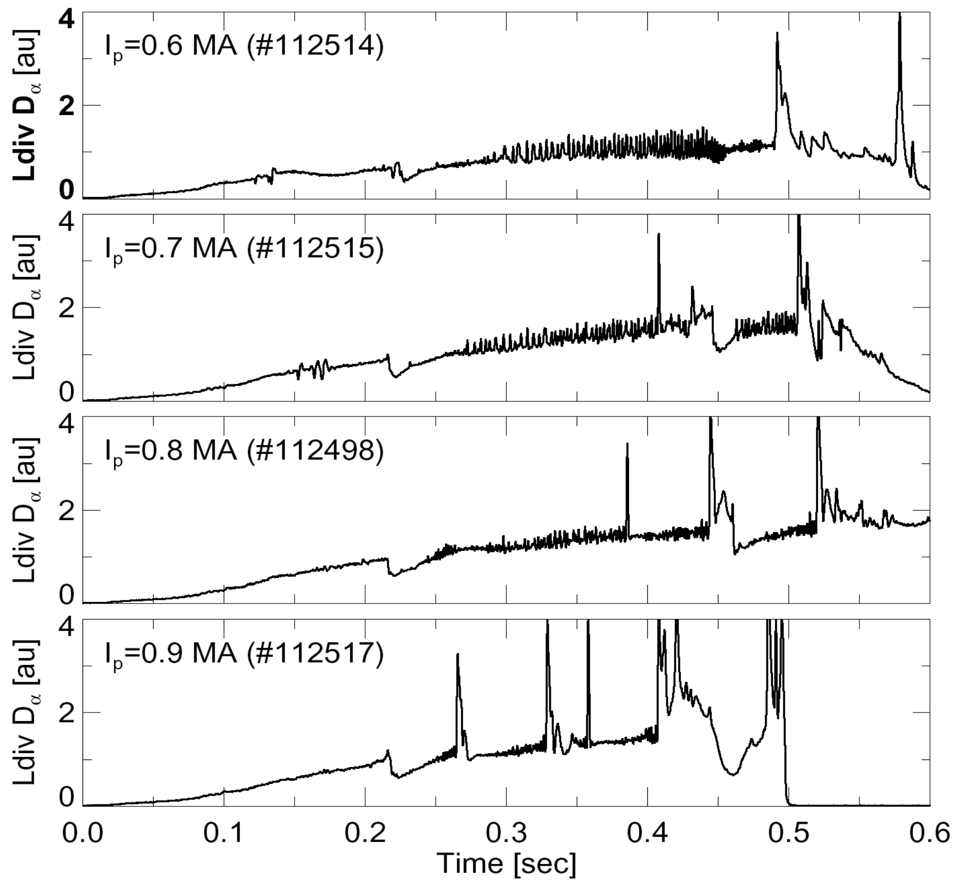


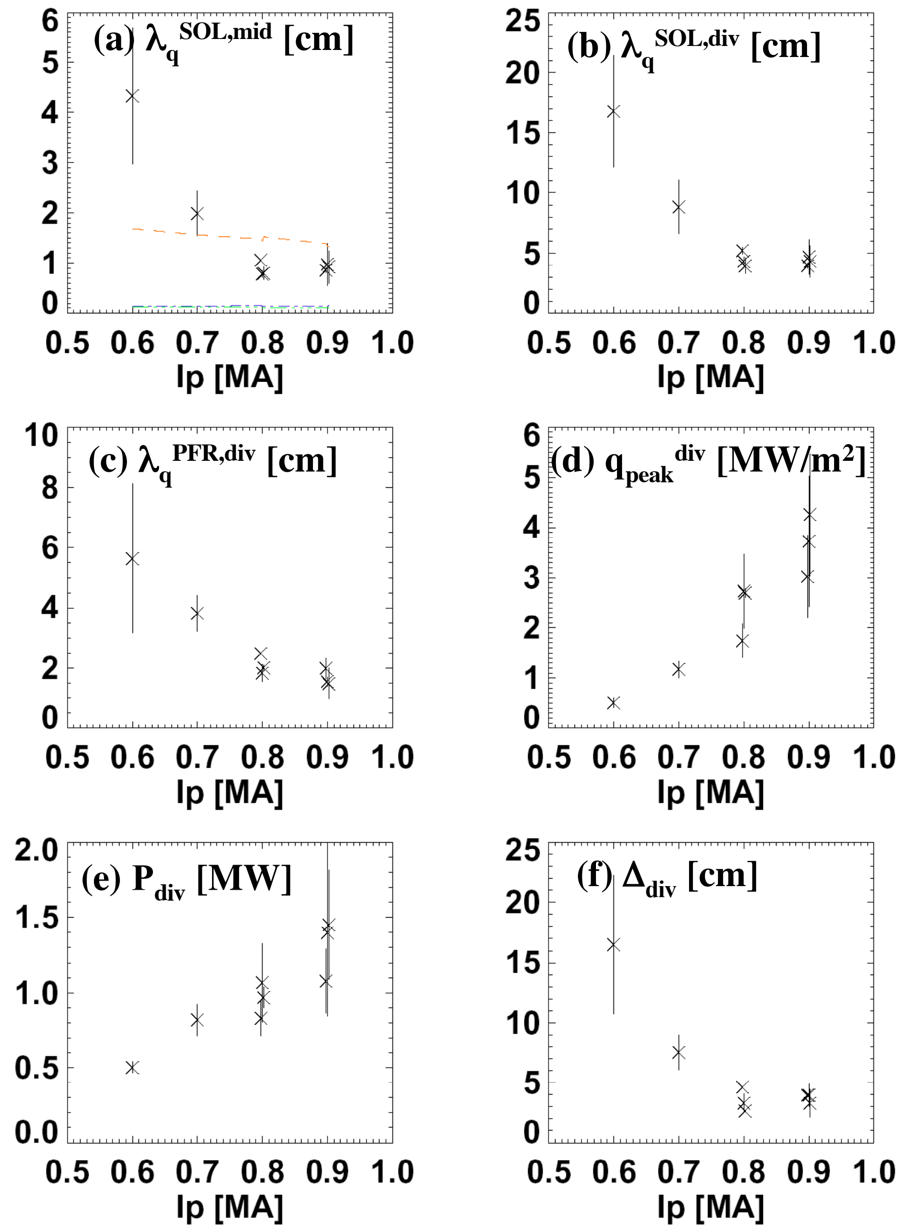


- Transition from "radiative divertor" to conduction-limited SOL at P_{loss} ~ 3 MW
- Panel (a) curves: red - model B1, blue - model D, green - model M (Counsell JNM 1999)

UC San Diego

Dramatic reduction of SOL width with increasing I_p





- $\lambda_q^{SOL,mid} \sim I_p^{-(2.3-3.8)}$
- P_{NBI}=4 MW, $3 < P_{loss} < 3.4$ MW
- Panel (a) curves: red - model B1, blue - model D, green - model M (Counsell JNM 1999)

UC San Diego

NSTX SOL heat flux width not well described by analytic SOL models

- Connor/ Counsell - model D/O collisional SOL: 0.1-0.2 cm

$\lambda_q^D[cm]=0.35q_{95}^{-0.1}R_m^{0.3}a_m^{0.4}P_{loss}^{-0.4}$

- Connor/ Counsell - model M collisional SOL: 0.1-0.17 cm

$\lambda_q^M[cm]=0.083q_{95}^{0.6}R_m^{1.0}a_m^{0.4}P_{loss}^{-0.4}$

- Connor/Counsell - model B1 collisionless SOL: 1-1.5cm

$\lambda_q^{B1}[cm]=0.3q_{95}^{0.73}R_m^{0.27}a_m^{-0.18}P_{loss}^{0.18}B_t^{-0.57}n_{sep}^{-0.18}$

- Kallenbach - multi-machine SOL width: 0.075cm

$\lambda_q^{AK}[cm]= (2/7)\lambda_{te}^{AK}=0.088R_m^{1.0}$

- Bohm cross-field transport ($\chi_\perp^{Bohm}\sim T_e/B_t$) within Borass two-point model predicts ~ 1-1.2 cm

NSTX SOL Scaling with Fast Probe

- Profiles of SOL plasma parameters (n_e and T_e) represent nature of cross field particle and heat transport
  → Fundamental SOL understanding
- Fast probe features 10 tips
- Can directly measure T_e, N_e, V_f, $V_{||}$, I_{sat} as well as Bdot (magnetic head)
- Can estimate $\tilde{\Gamma}_\perp$ and $\tilde{q}_\perp^{conv}$ $(= \frac{3}{2} T_e \tilde{\Gamma}_\perp)$
- Good LCFS position crucial and new T_e-constrained EFIT is now available (shift of 2-5 cm outward)
- Control of LCFS position also improved

SOL has two characteristic scale lengths

- 2 exponential curves in a SOL density profile: “Near SOL” and “Far SOL”
- Steep gradient in the ‘Near SOL’ for 2-3 scale lengths
- Flatter gradient in the ‘Far SOL’, Intermittency dominates
- Probe can plunge to Near SOL, possibly all the way to the separartrix, for $P_{NBI} \leq 3$ MW (baseline for scans, done with reduced voltage)
- For $P_{NBI} \geq 4$ MW, probe may just inside or at the Near/Far SOL boundary, so comparison with IR camera data is more limited
- Probe optimized for edge field line pitch +/- 5-7^{o}
  - ➢ Scans at fixed q95 give best quality data during a run day
  - ➢ Probe head is rotatable on overnight basis

Probe data with limited n_e scan and limited P_{in} scan exists

- Heat losses in the attached SOL plasma

→ Parallel conduction
→ Perpendicular conduction & convection
→ Radiation

n_e scan and P_{in} scan experiment:

- Increasing n_e
  - → Particle input increases
  - → Convective perp. heat transport increases
  - → Thicker heat flux SOL width, particularly in detachment
- Increasing P_{in}
  - → Heat input increases if radiation increase is modest
  - → For a given n_e level, higher peak heat flux density & thinner heat flux SOL width

UC San Diego

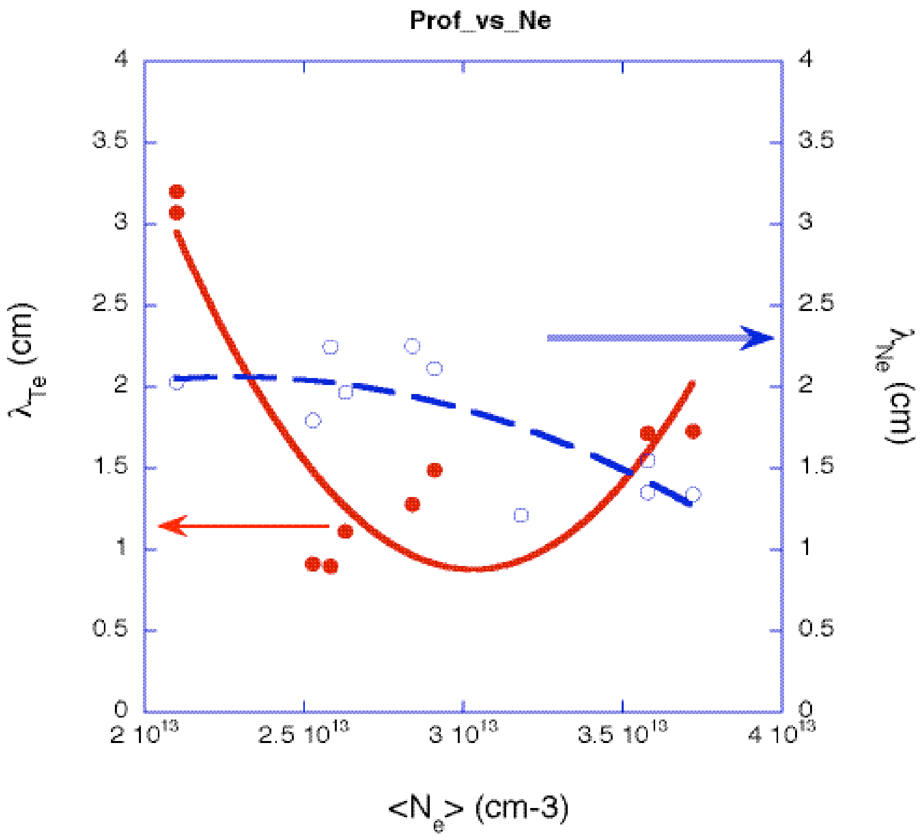
ornl Oak Ridge National Laboratory

T_e and n_e SOL Width Scaling with line-average density

- Took profiles in L-mode plasmas
- Measured with ~1.5 mm resolution (every ~1 ms)
- Fit offset exponentials
- Analytical expressions used:

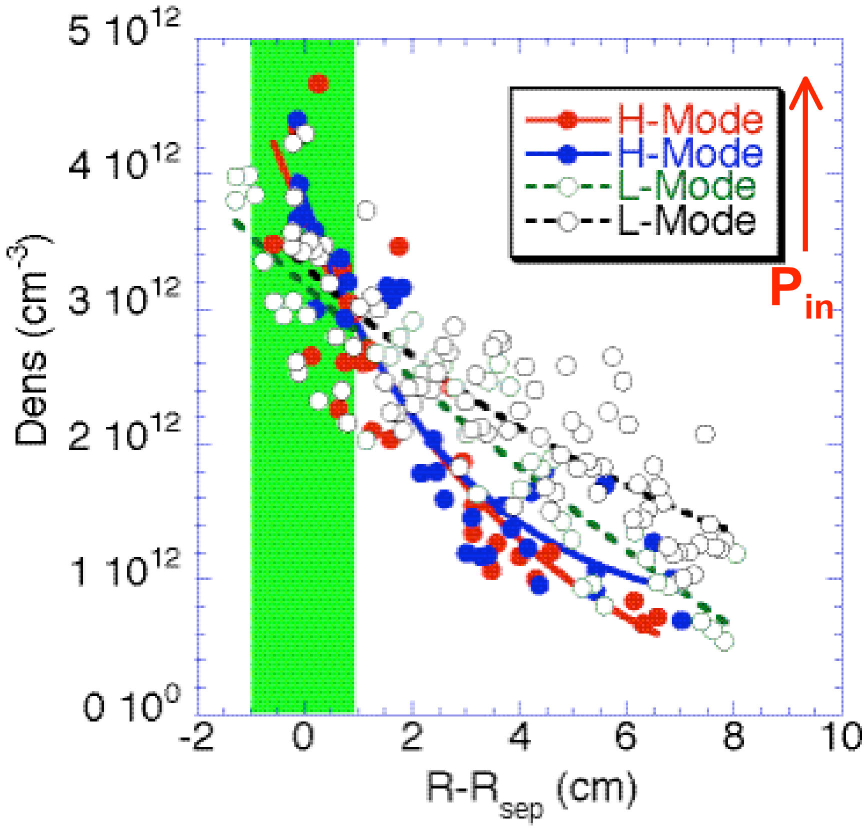
$$n_e = n_{e0} + n_{e1} e^{-(r-r_{sep})/\lambda_n}$$

$$T_e = T_{e0} + T_{e1} e^{-(r-r_{sep})/\lambda_T}$$



- Density decay length is ~1.5-2 cm
- Drops slightly with density
- Temperature decay length is ~1.0-3.0 cm, with non-monotonic behavior

Density profile steepens with P_{in}



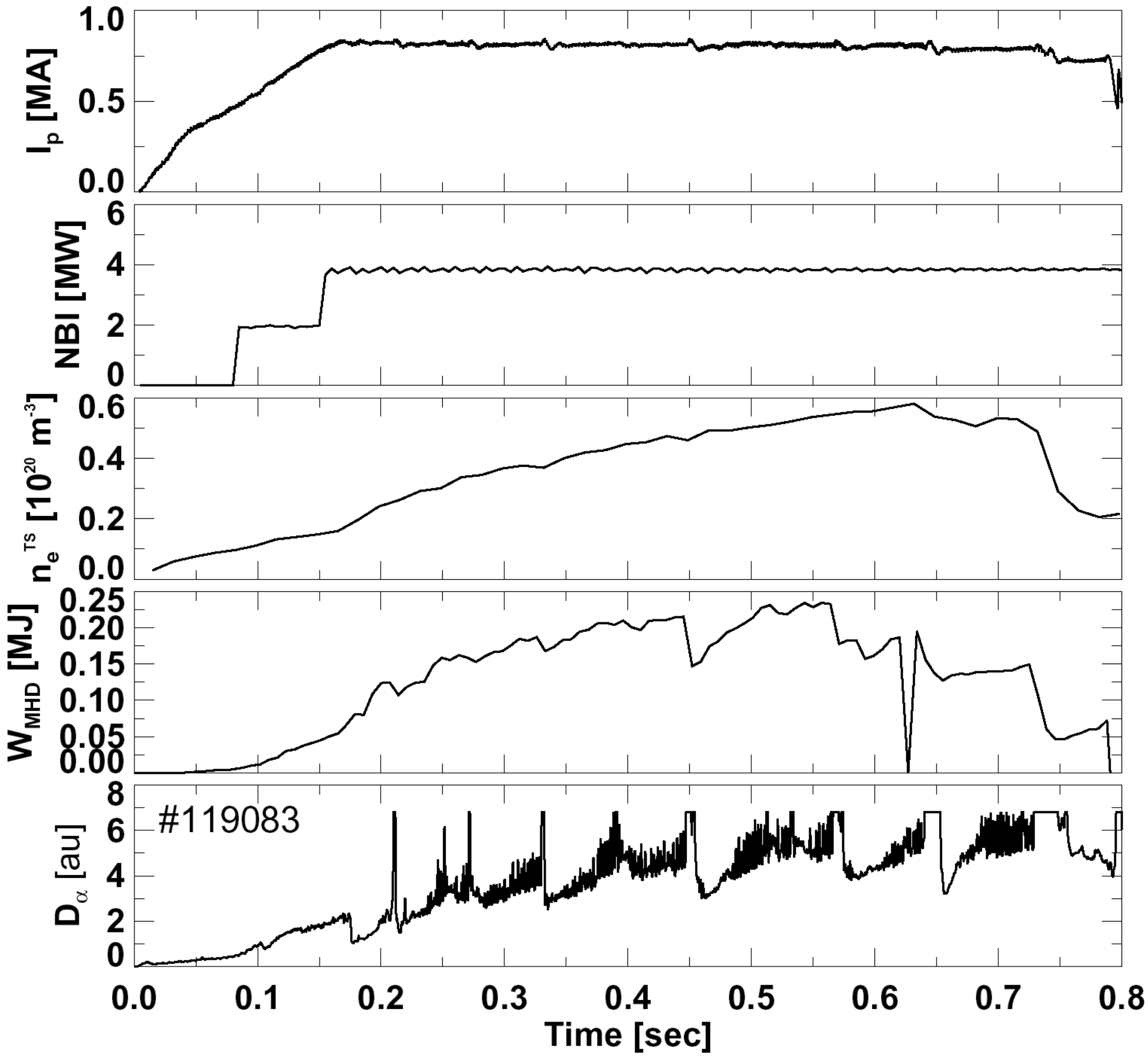
Density SOL decay length is reduced by factors of ~2-3 with increasing P_{in}.

Proposed Run Plan - priority on I_p scan at fixed q95

1. Establish baseline: 0.8 MA, 0.45 T; P_{NBI}=3, 5 MW (5)
   - Start from #119083, 1100-1200 Torr on CS
2. I_p scan at approximately fixed q95, P_{NBI}=3, 5MW (15)
   - 1.0 MA, 0.55 T
   - 0.6 MA, 0.35 T
   - 1.1 MA, 0.55 T
   - 0.9 MA, 0.5 T
   - 0.7 MA, 0.4 T
3. Time allowing: B_t scan at fixed I_p, P_{NBI}=5 MW (5)
   - 0.8 MA, 0.55 T; 0.8 MA, 0.35 T

Backup

Baseline LSN Shot Characteristics



- Increase P_{HFS} from 1000 torr to 1100-1200 torr to suppress large events
- Drop power to 3 MW for probe penetration (reduced voltage, not pulse/width modulation)