Comparison of Pedestal Stability on the Power Scrape-Off Layer Width in NSTX

Travis K Gray (ORNL),

R Maingi[1], J-W Ahn1, TH Osborne[2], AG McLean[3] and the NSTX Research Team

[1]Oak Ridge National Laboratory
[2]General Atomics
[3]Lawrence Livermore National Laboratory

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Focused efforts have confirmed the importance of plasma current scaling for both pedestal gradients and divertor heat flux widths

- Results of coordinated U.S. experiments to understand the scaling of:
  - the divertor power flux width, λ_q and
  - the H-mode pedestal with engineering parameters
- λ_q was found to scale ~ B_{pol}^{mid} under attached divertor conditions
- Pedestal height was found to be well described by Peeling-Ballooning modes
- Given the common dependence on Ip on both λ_q and the pedestal, a correlation is possible

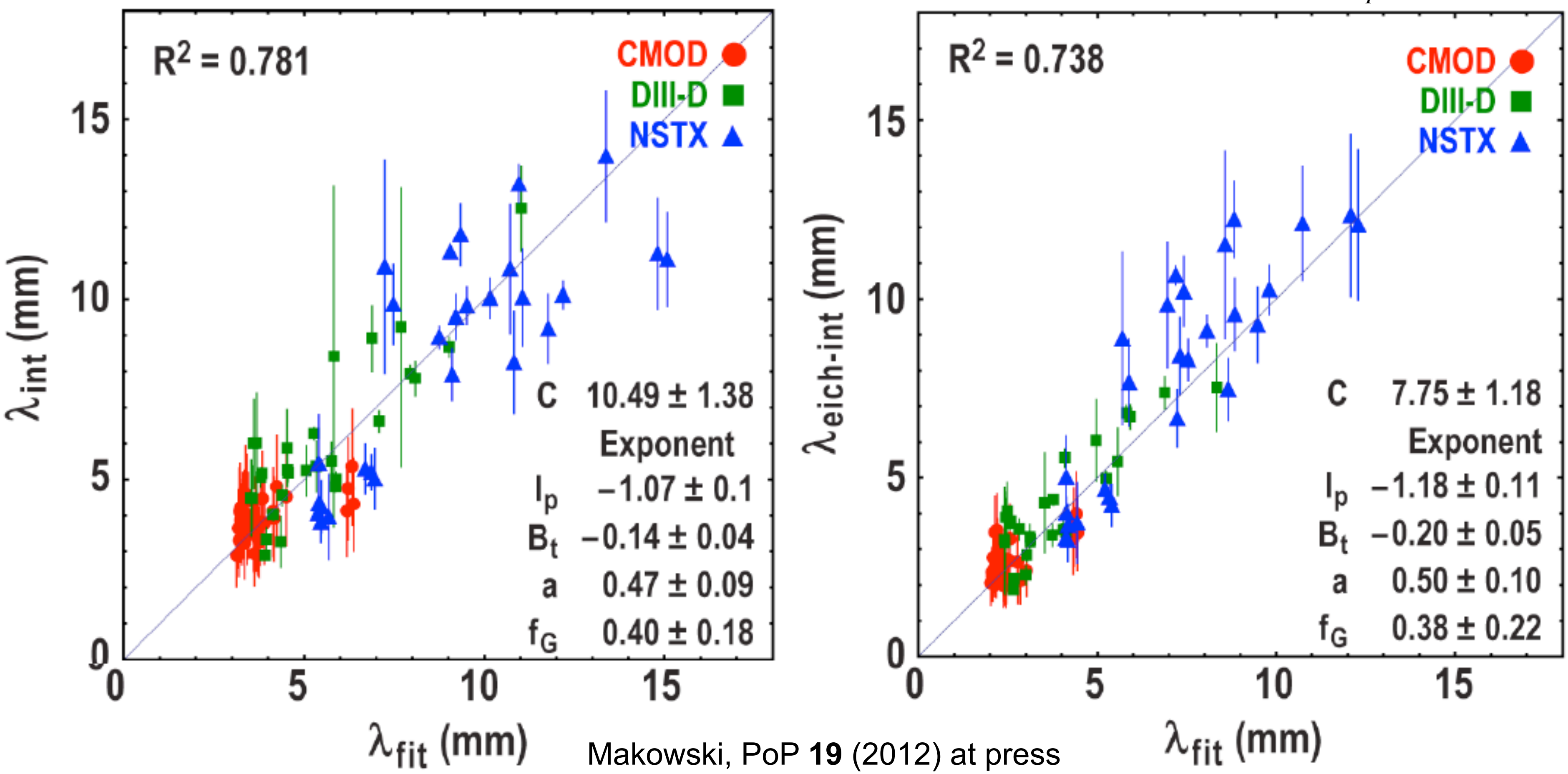
Combined scaling from US tokamaks highlights the Ip and minor radius (a) dependence

$$\lambda_{fit} = C \cdot I_p^{e_I} \cdot B_t^{e_B} \cdot a^{e_a} \cdot f_G^{e_f},$$

$$f_G = n_e / (I_p / \pi a^2)$$

$$\lambda_{eich-\mathrm{int}} = \frac{1}{q_{\parallel 0}} \int_{-\infty}^{\infty} [q_{\parallel}(s) - q_{bkg}] ds$$

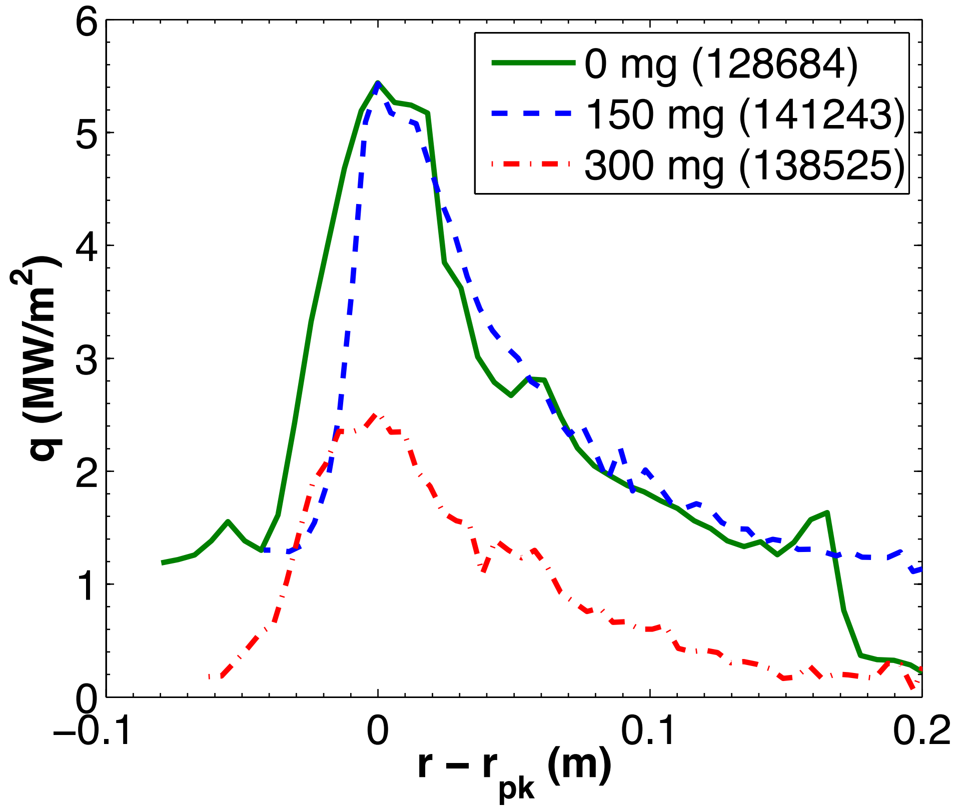
$$\approx \lambda_{sol} + 1.64 w_{pvt}$$



Makowski, PoP **19** (2012) at press

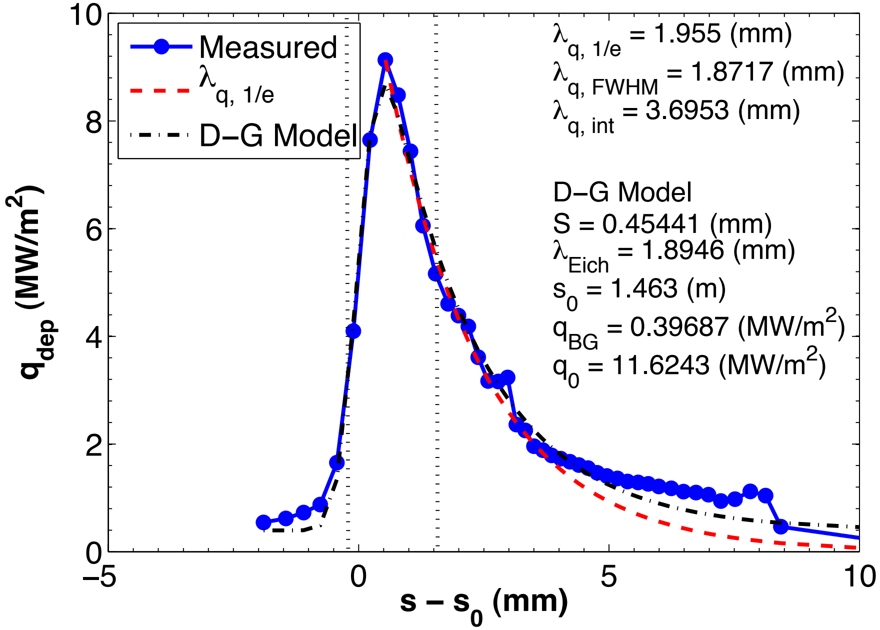
In NSTX, lithium wall conditioning has also been shown to have a strong impact on λ_q

- 0 mg (boronized) and 150 mg of Li yield similar heat fluxes (inter-ELM averaged)
- λ_q contracts with addition of 150 mg of Li
  - Likely due to the elimination of small Type V that can be ubiquitous in boronized conditions [Maingi2005]
- With sufficient Li (300 mg), heat flux is also reduced
  - Measurements made with DBIR camera to account for surface emissivity effects
  - λ_q contracts further still



TK Gray, IAEA-FEC ...

There are numerous definitions for the SOL width, λ_q



- Integral: $\lambda_{q,\,int}$
  - Numerical integration of radial heat flux profile
  - Assumes axisymmetric heat deposition profile

$$\lambda_{q,int} = \frac{\int \left(q(s) - q_{\mathrm{BG}}\right) ds}{q_{\max}}$$

- Diffusive-Gaussian (D-G) Model[Eich2012]
  - Simple semi-empirical model
  - Assumes λ_q is an exponential in the SOL before entering the divertor

$$q(\bar{s}) = q_0 \exp\left(-\frac{\bar{s}}{\lambda_q f_{exp}}\right)$$

  - The exponential "diffuses" into the private flux region as it enters the divertor
  - No mechanism for this diffusion is put forth
    - But is clearly observed in all divertor footprints
  - 5 free parameters which require nonlinear least squares fitting to determine

$$q(\bar{s}) = \frac{1}{2} q_0 \exp\left(\left(\frac{\mathrm{S}}{2\lambda_q f_{exp}}\right)^2 - \frac{\bar{s}}{\lambda_q f_{exp}}\right) \mathrm{erfc}\left(\frac{\mathrm{S}}{2\lambda_q f_{exp}} - \frac{\bar{s}}{\mathrm{S}}\right) + q_{\mathrm{BG}}$$

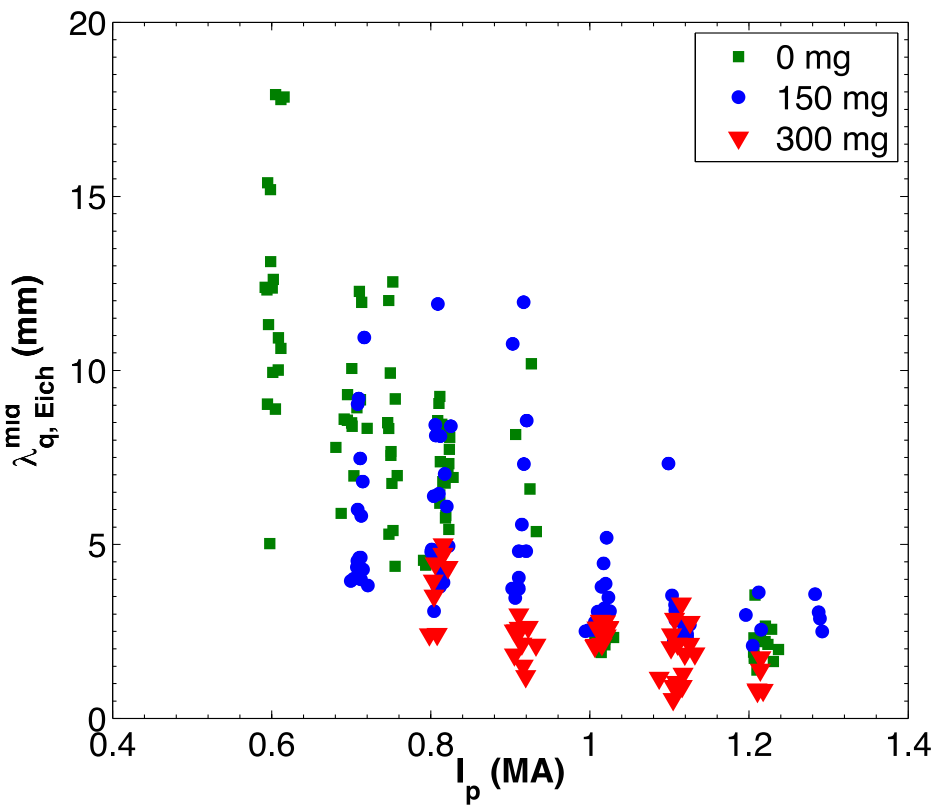
s = radial coordinate
s_0 = Strike Point Location

$$\bar{s} = s - s_0$$

q_0 = peak heat flux
q_{BG} = background heat flux
λ_q ($\lambda_{q,\,Eich}$) = e-folding length of q in SOL
S = Gaussian diffusion parameter

$\lambda_{q,\ Eich}$ contracts with I_p

- Diffusive-Gaussian analysis used to analyze heat flux profile
  - $\lambda_{q,\ Eich} \sim \lambda_{q,\ int}$
- $\lambda_{q,\ Eich}$ is similar between 0 and 150 mg data
  - Perhaps less scatter in the data
  - This suggests that λ_q is similar at the outer midplane (OMP) for 0 and 150 mg data
  - But their must be more diffusion in the 0 mg data to achieve larger $\lambda_{q,\ int}$'s
- 300 mg data is still contracted under this analysis

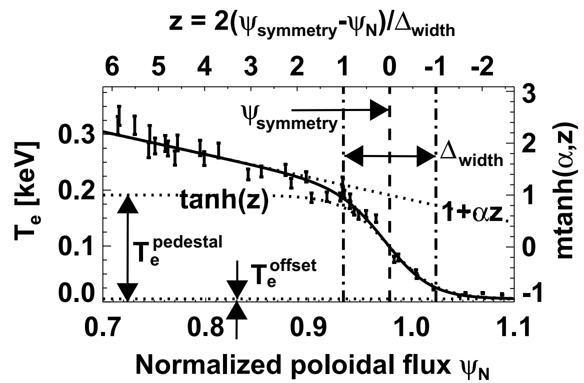


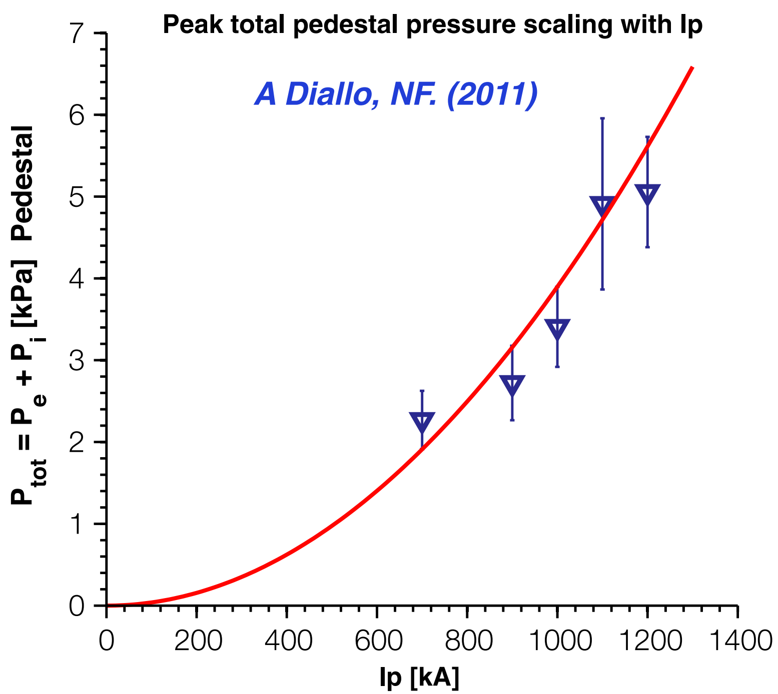
At high I_p, for all Li deposition amounts, $1 \leq \lambda_q \leq 3.5$ mm

Could Peeling-Ballooning (P-B) or Kinetic Ballooning Modes (KBMs) set λ_q?

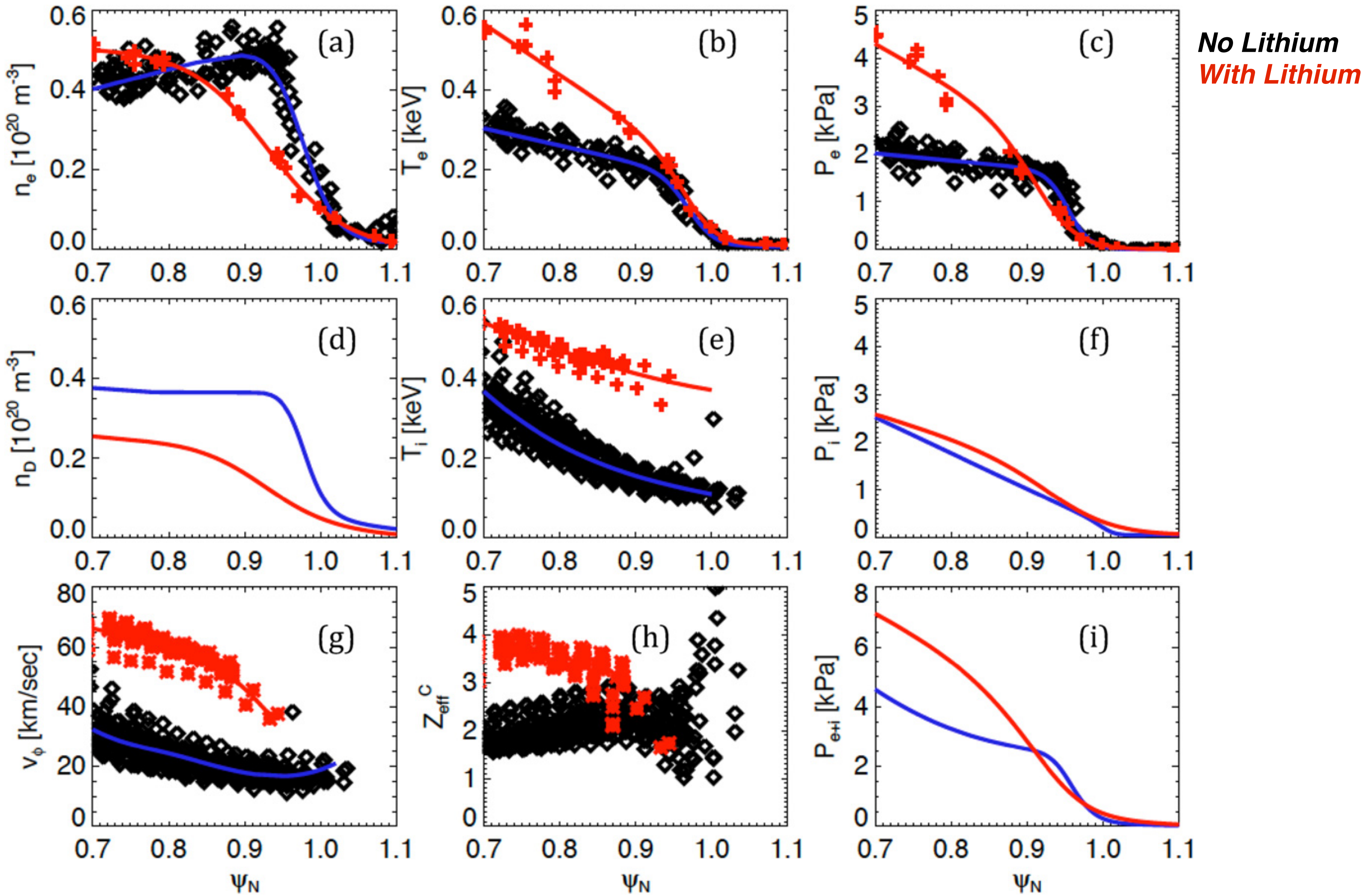
- Pedestal profiles are characterized using modified TANH functions
- The peak pedestal pressure is found to scale as ~ I_p^2
- The pedestal pressure height is set by Peeling-Ballooning physics
- Useful to describe the pedestal with a normalized pressure gradient:

$$\alpha = -Rq^2 \frac{d\beta}{dr}$$



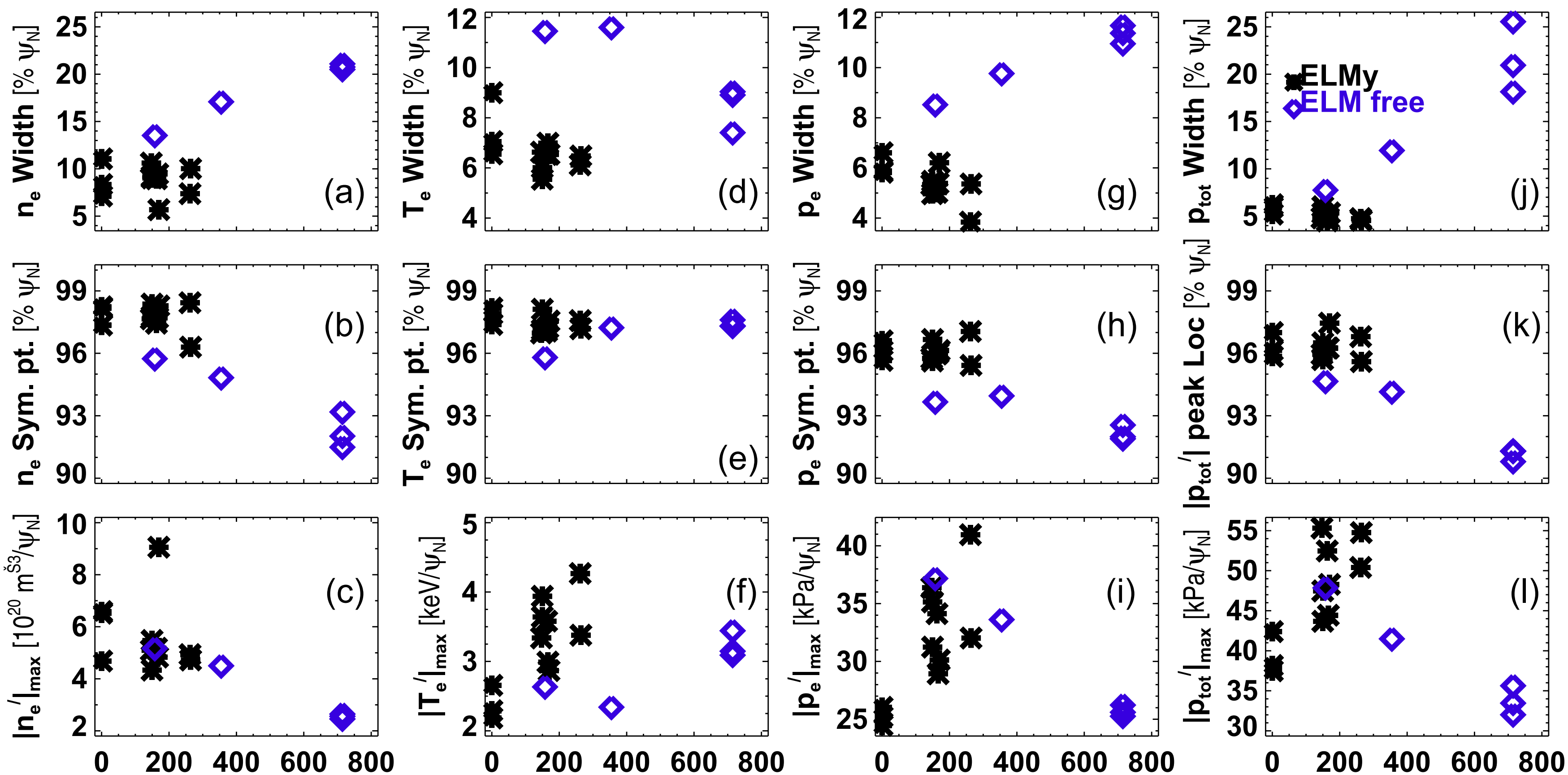


Lithium wall conditioning has a strong effect on the electron density (and therefore pressure) pedestal



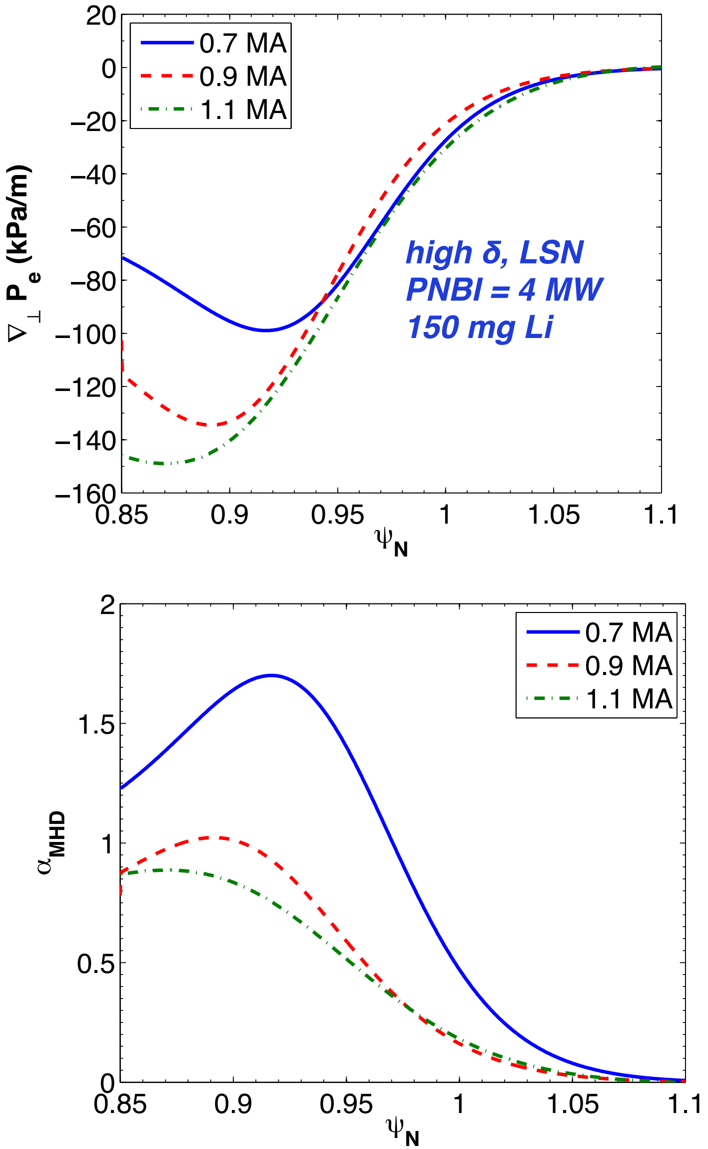
R Maingi, NF (2011)

Increasing amounts of Li have a nearly continuous effect on the pedestal



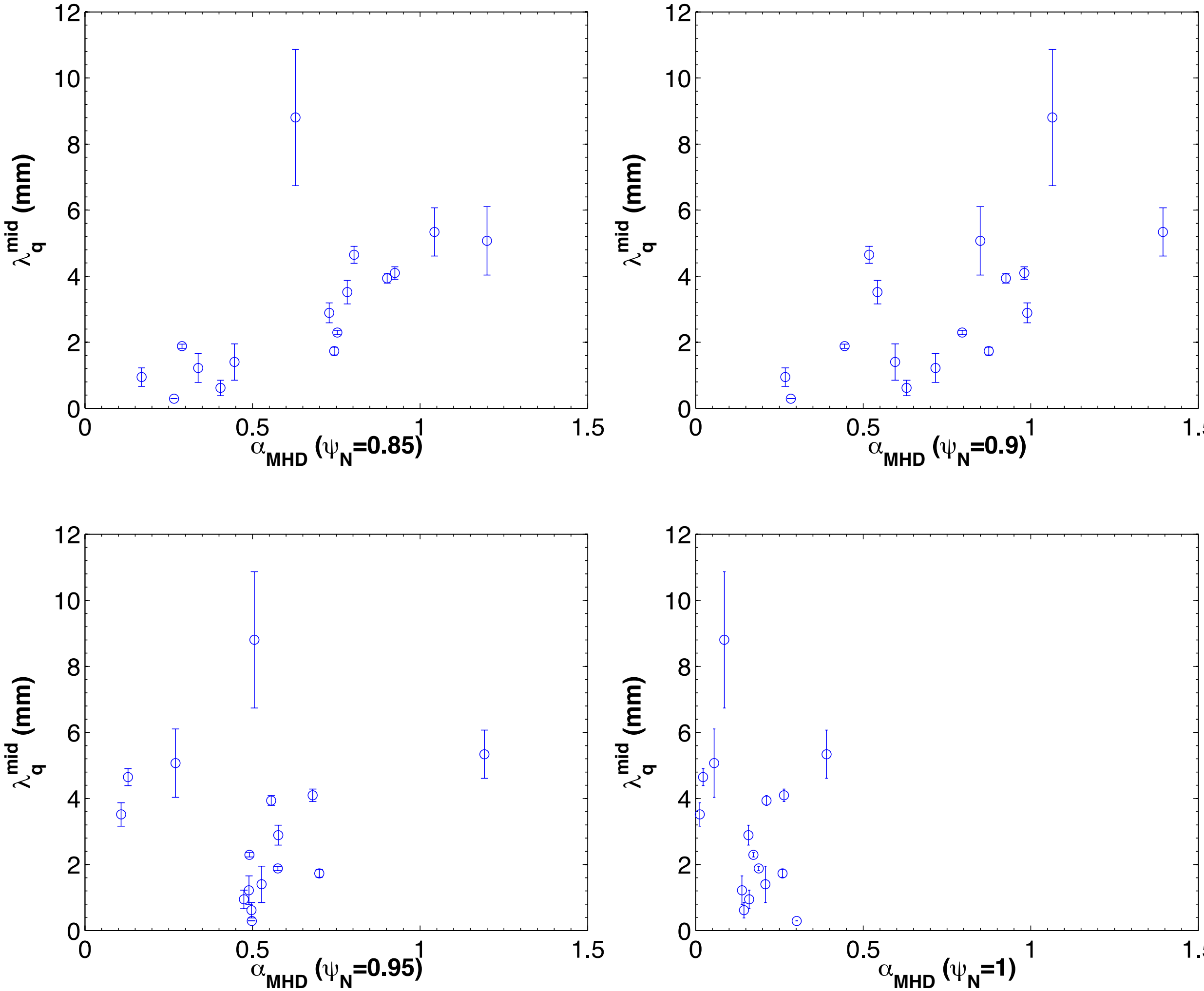
D Boyle, PPCF. (2012)

- With increasing I_p, the peak of $-\nabla_\perp P_e$ increases
- $\nabla_\perp P_e$ near the seperatrix remains largely unchanged at -20 kPa/m with I_p
- According to Peeling-Ballooning theory, the onset of ELMs occur when a critical value of the normalized pressure gradient occurs, α_{crit}
  - Possible that P-B sets the edge transport into the SOL even before the critical value is reached



Preliminary analysis shows only a weak correlation between λ_q and the α parameter

- Comparison of λ_q's from from a range of discharges
  - high δ, LSN
  - P_{NBI} = 4 MW
  - $0.7 \leq I_p \leq 1.2$ MA
  - 150 and 300 mg of Li
- Only a weak correlation is found with α_{MHD} evaluated at ψ_N = 0.85 or 0.9



Conclusions

- λ_q has been found to scale strongly with I_p and pre-discharge Li wall conditioning
  - I_p dependence varies with amount of pre-discharge Li wall conditioning
  - At high I_p, λ_q ~ 2 - 4 mm regardless of amount of Li deposited

- Likewise, the electron pressure pedestal varies with I_p and Li

- However, only a weak correlation between λ_q and α has been found at ψ_N = 0.85 or 0.9
  - No correlation has been found with α evaluated closed to the seperatrix

References (will update these)

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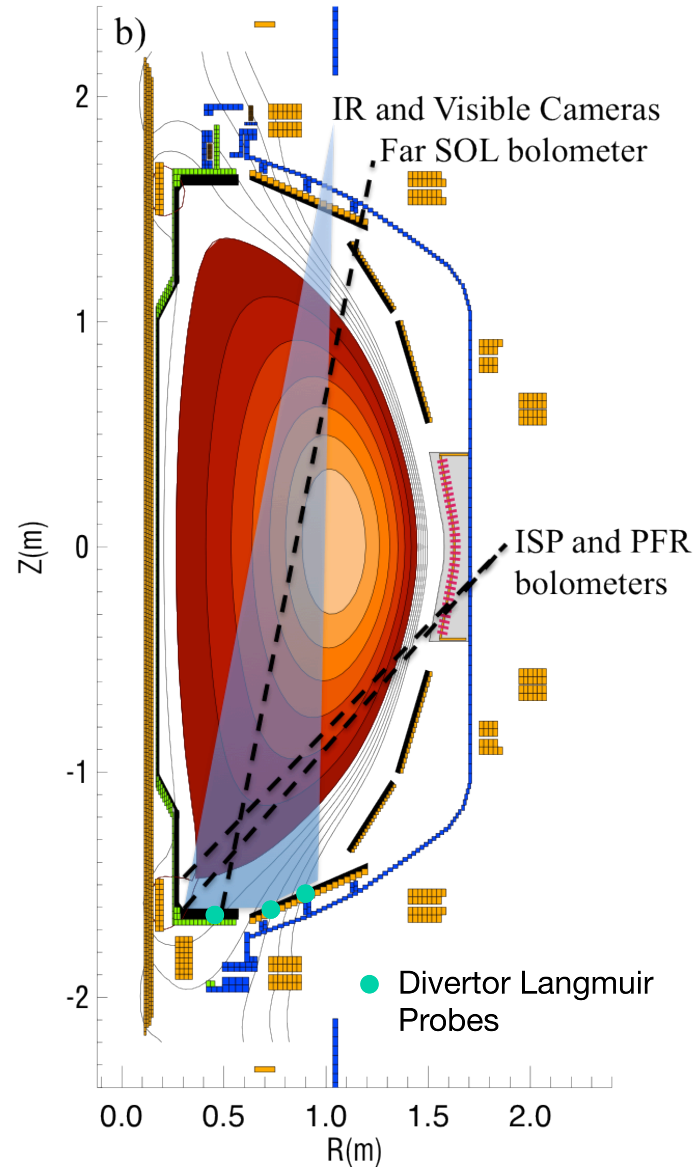
NSTX Divertor Diagnostics

- 2, 30 Hz IR cameras
  - 1 viewing the lower divertor, 1 the upper
  - sensitive to 6 - 13 μm
- 1 Fast IR camera (≤ 16 kHz)
  - viewing the lower divertor
  - sensitive to 6 - 13 μm
  - equipped with dual band optics
- 2 Fast Phantom cameras (≤ 100 kHz)
  - each viewing nearly the entire lower divertor
  - bandpass filtered
- 2 1D CCD array cameras
  - measuring Dα and Li II emission
- 3 channels of lower divertor bolometry
- Flush mounted divertor Langmuir probes



The Dual-Band IR Camera Allows Measurement of Divertor Surface Temperature with Variable Surface Emissivity

- The addition of lithium complicates the measurement of divertor surface temperature, T_{surf}
  - Li emissivity (clean) ~ 0.1
  - Graphite ~ 0.8
  - Lithium and Carbon are eroded and redeposited constantly through out the discharge
- Using a Santa Barbra Focal Plane Camera
  - 128x128 pixels
  - frame rate ≤ 16 kHz (typical operation at 1.6 kHz with dual band optics)
- 2 different IR wavelength bands are imaged simultaneously[McLean 2012]
  - MWIR: 7 - 10 μm
  - LWIR: 10 - 13 μm
- The ratio of the 2 bands yields $T_{surf}(r,t)$
  - Assumes the surface emissivity is similar across both wavelength bands
  - Not a bad assumption for a diffuse, grey body emitter
- Once T_{surf} is known, heat flux can be calculated
  - 2D finite difference calculation (THEODOR)