NSTX-U

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The dependence of discharge performance on pre-discharge lithium evaporation in high triangularity H-mode discharges in NSTX

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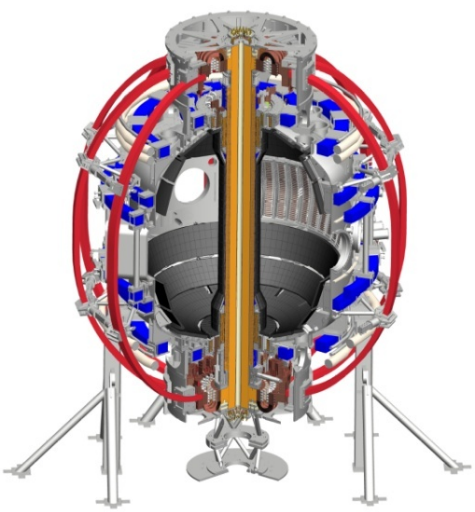
R. Maingi, S.M. Kaye, T.H. Osborne, and the NSTX Team

PPPL PRINCETON PLASMA PHYSICS LABORATORY

55th Annual Meeting of the Division of Plasma Physics
American Physical Society
Denver, CO: 11-15 November 2013



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Power and particle exhaust a key challenge for future devices

- Liquid metals are being studied at PPPL as an alternative to solid PFCs for future devices

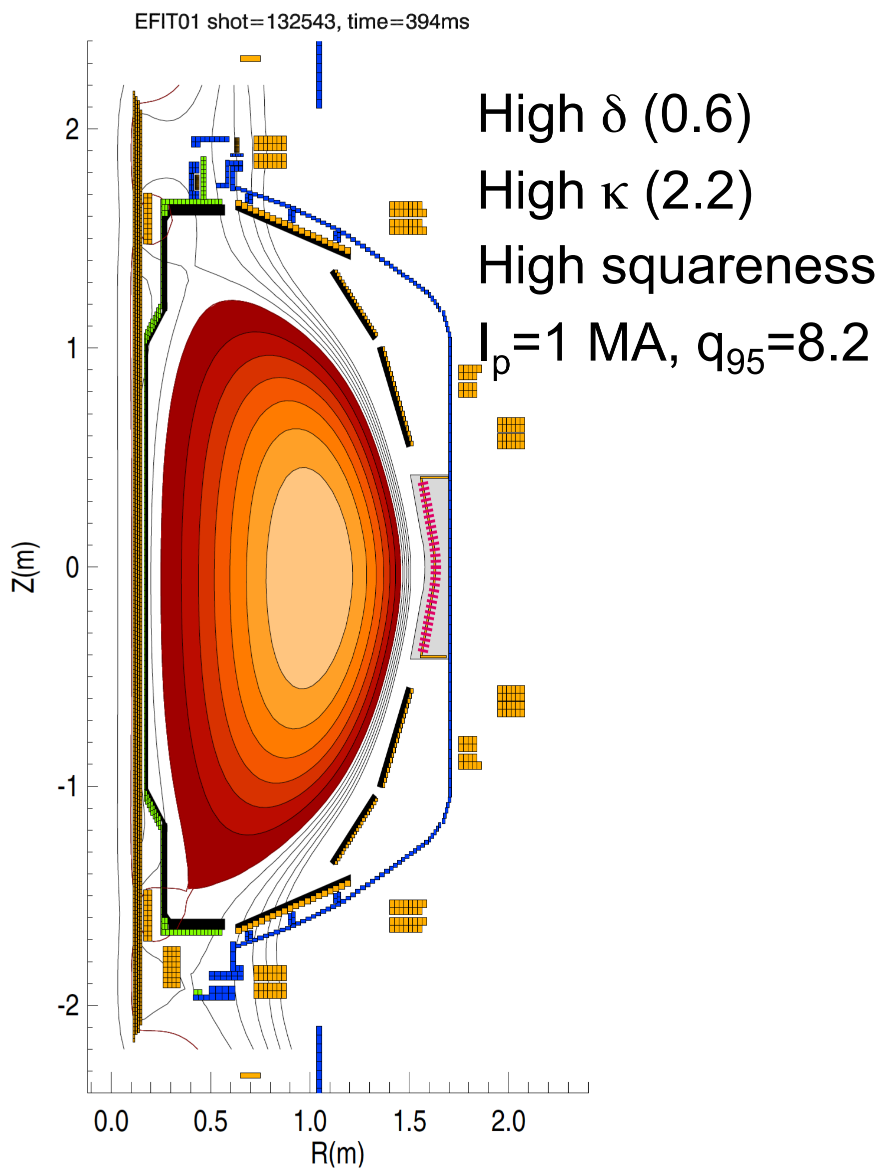
- NSTX used lithium wall coatings (evaporative and liquid) to test the efficacy of lithium in particle and power exhaust
  - Lithium enables reduced recycling from PFCs
  - Lithium will be important research line in NSTX-Upgrade, which is scheduled to commence operation in FY2015

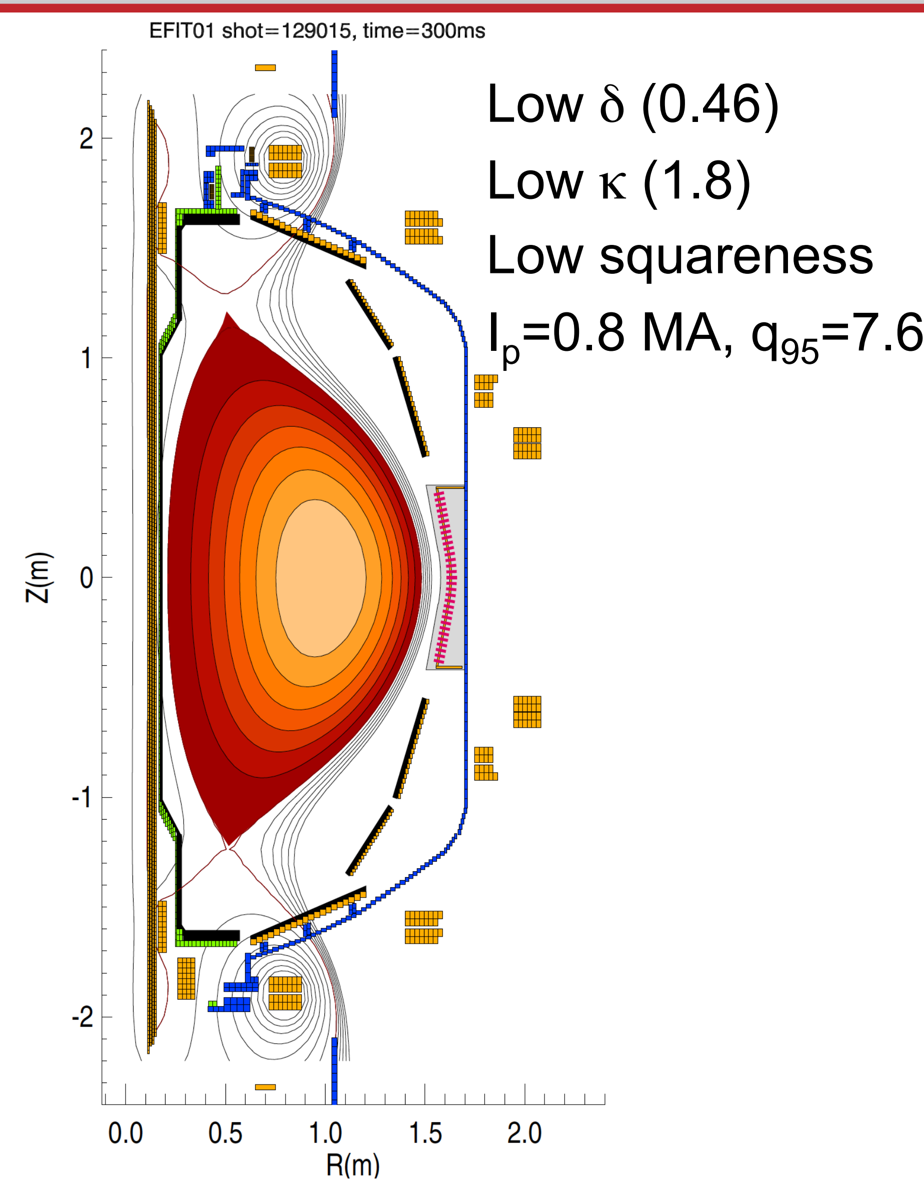
Plasma characteristics and stability improved with increasing lithium evaporation in strongly shaped NSTX discharges

- Lithium evaporated before each discharge
  - Amount scanned, as in weakly shaped discharge studies
  - No liquid lithium divertor results in this talk
- Global characteristics changed
  - Recycling: D_α declined in all measured views
  - Energy confinement (τ_E, H-factor) improved
  - When discharges were ELM-free, radiated power increased with time *(we developed several techniques to ameliorate this problem)*
- Edge n_e, T_e, pressure profiles changed
  - Reduction in edge n_e gradient changed edge P', improving stability in weakly shaped discharges; likely to be similar here

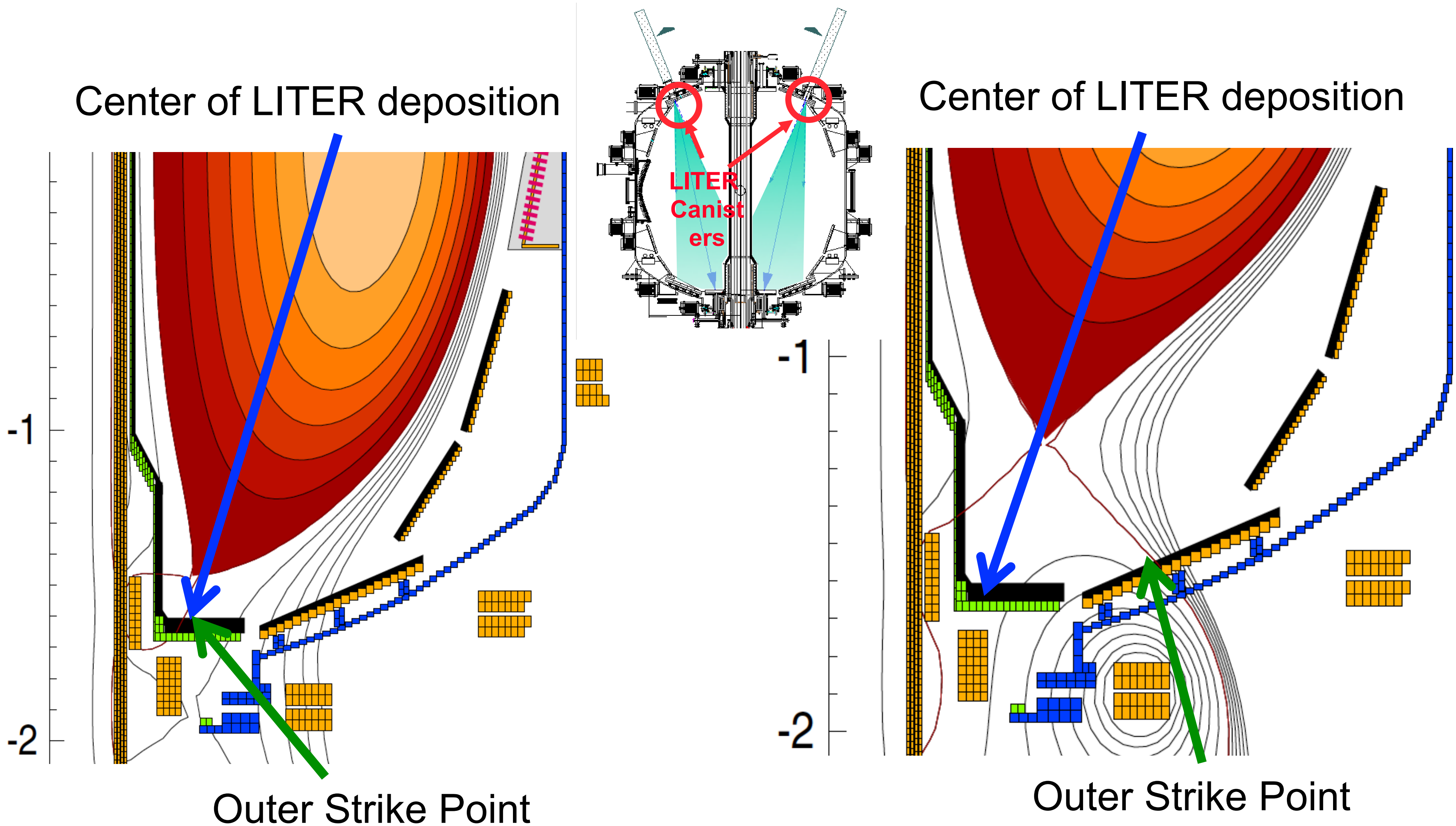
1. *Effect on individual discharges*
2. *Trends vs pre-discharge lithium*
3. *Effect on profiles*

New dataset from highly shaped plasmas as envisioned in NSTX-U, and for future STs

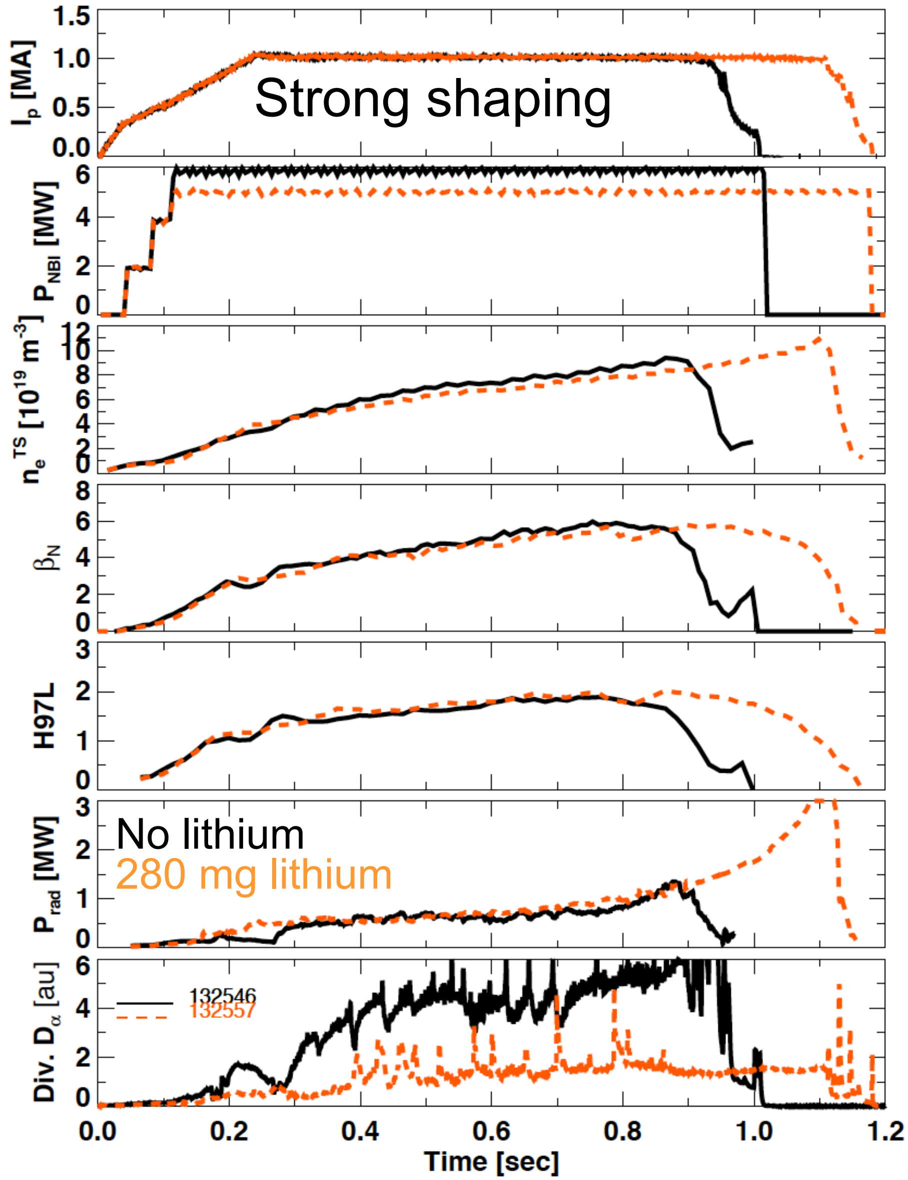




LITER deposition centroid relatively far from outer strike point in lower triangularity discharge

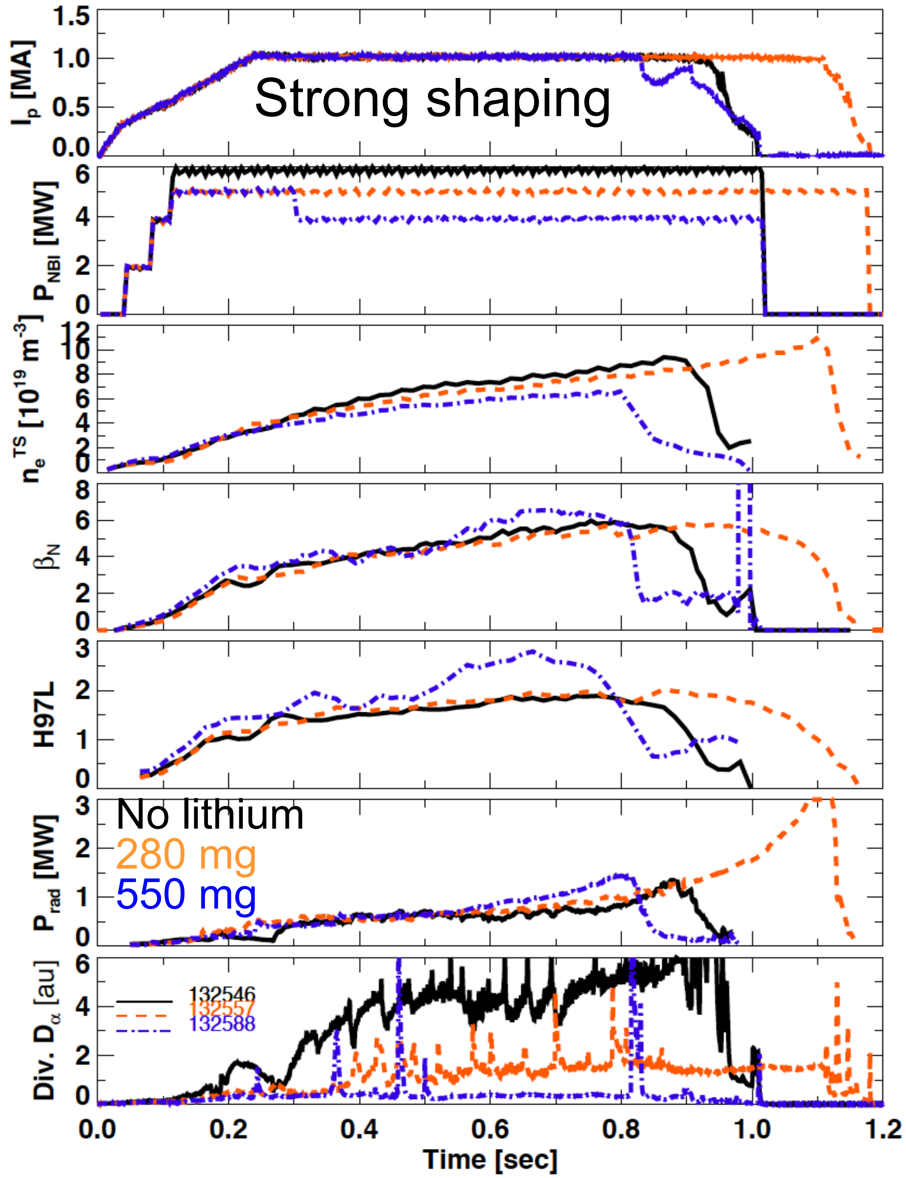


Performance of strongly shaped discharges improved with lithium conditioning, similar to weakly shaped ones



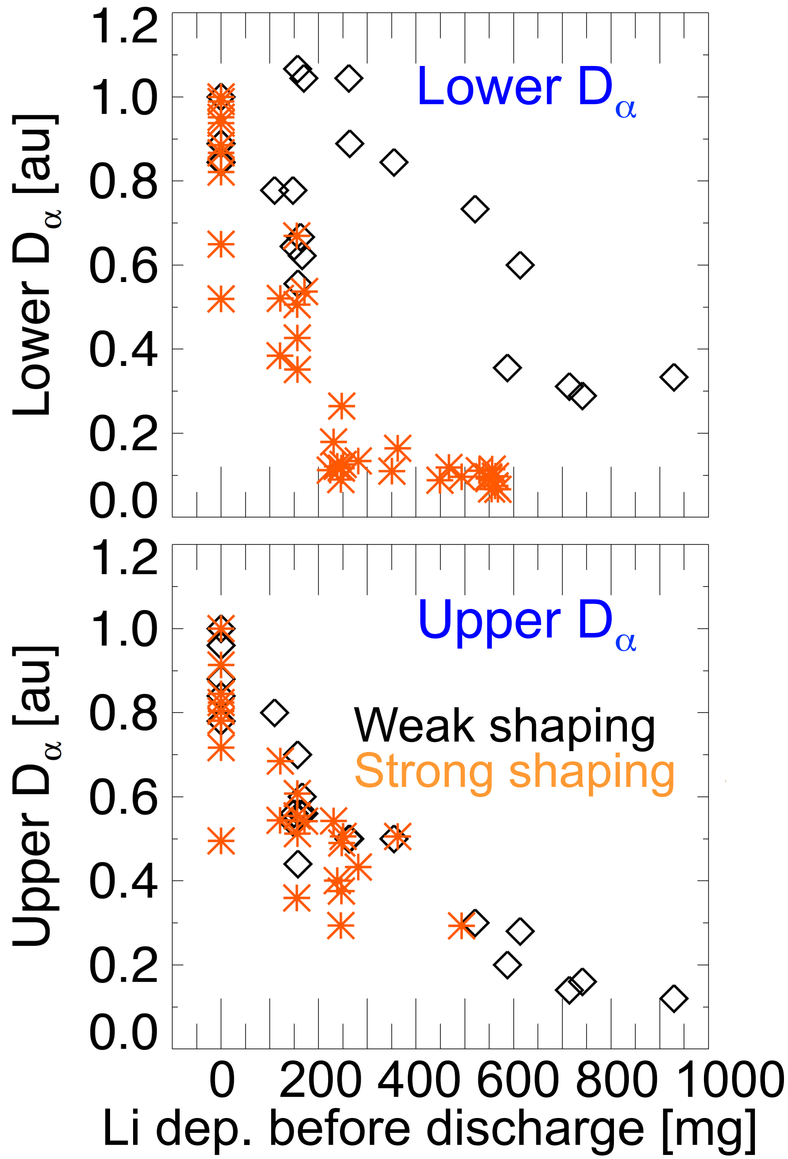
- Duration extended
- Reduced P_{NBI}
- Reduced dN/dt
- Comparable stored energy
- Comparable confinement
- Increasing P_{rad}
- Reduced recycling, long small ELM phase

Performance of strongly shaped discharges improved even more with increased lithium, similar to weakly shaped ones



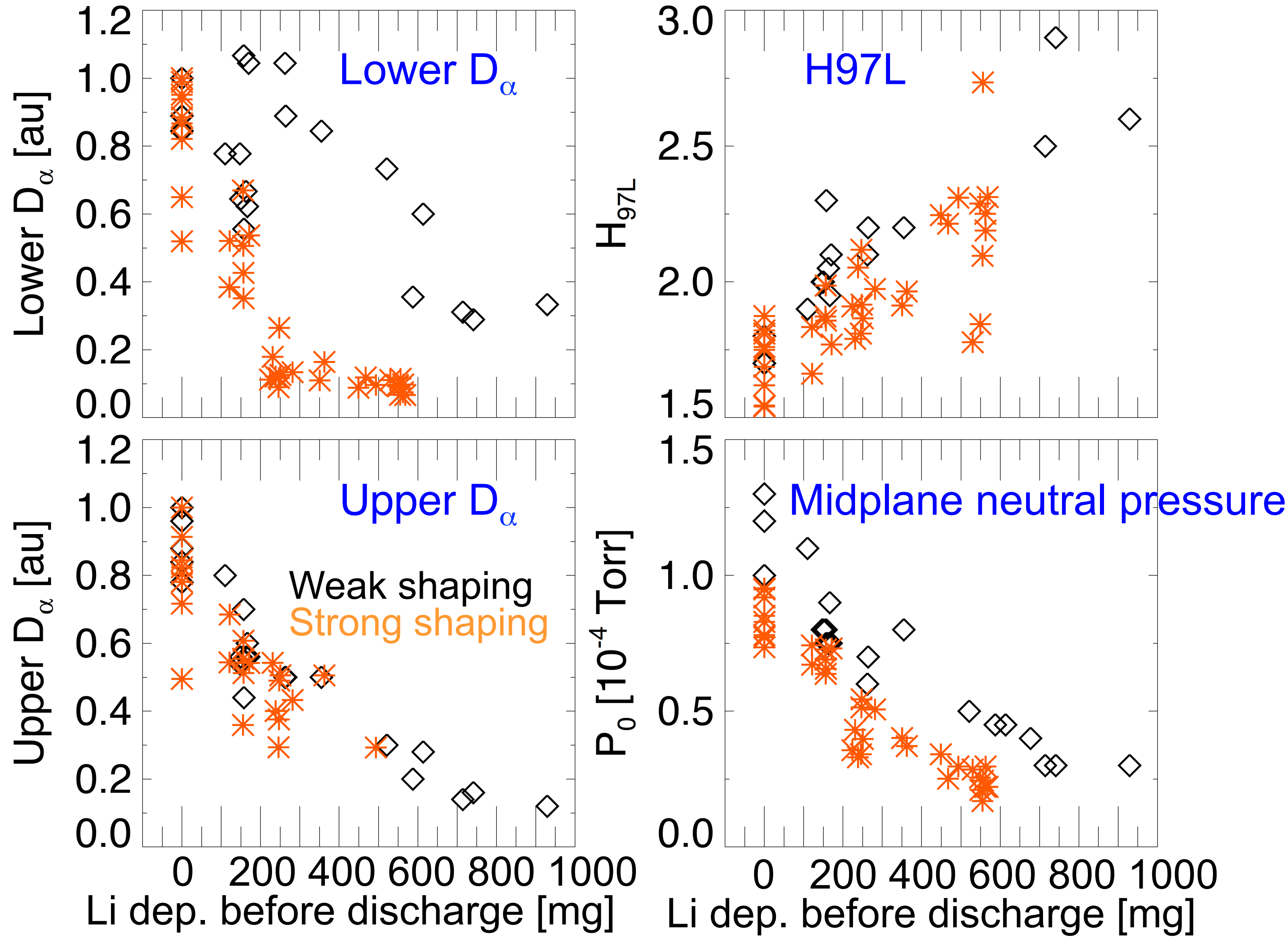
- I_p duration not quite optimized with higher lithium
- Reduced P_{NBI}
- Reduced dN/dt
- Comparable stored energy
- Higher confinement
- Increasing P_{rad}
- Reduced recycling, long ELM-free phases

D_α decreased with increasing pre-discharge lithium evaporation in all data

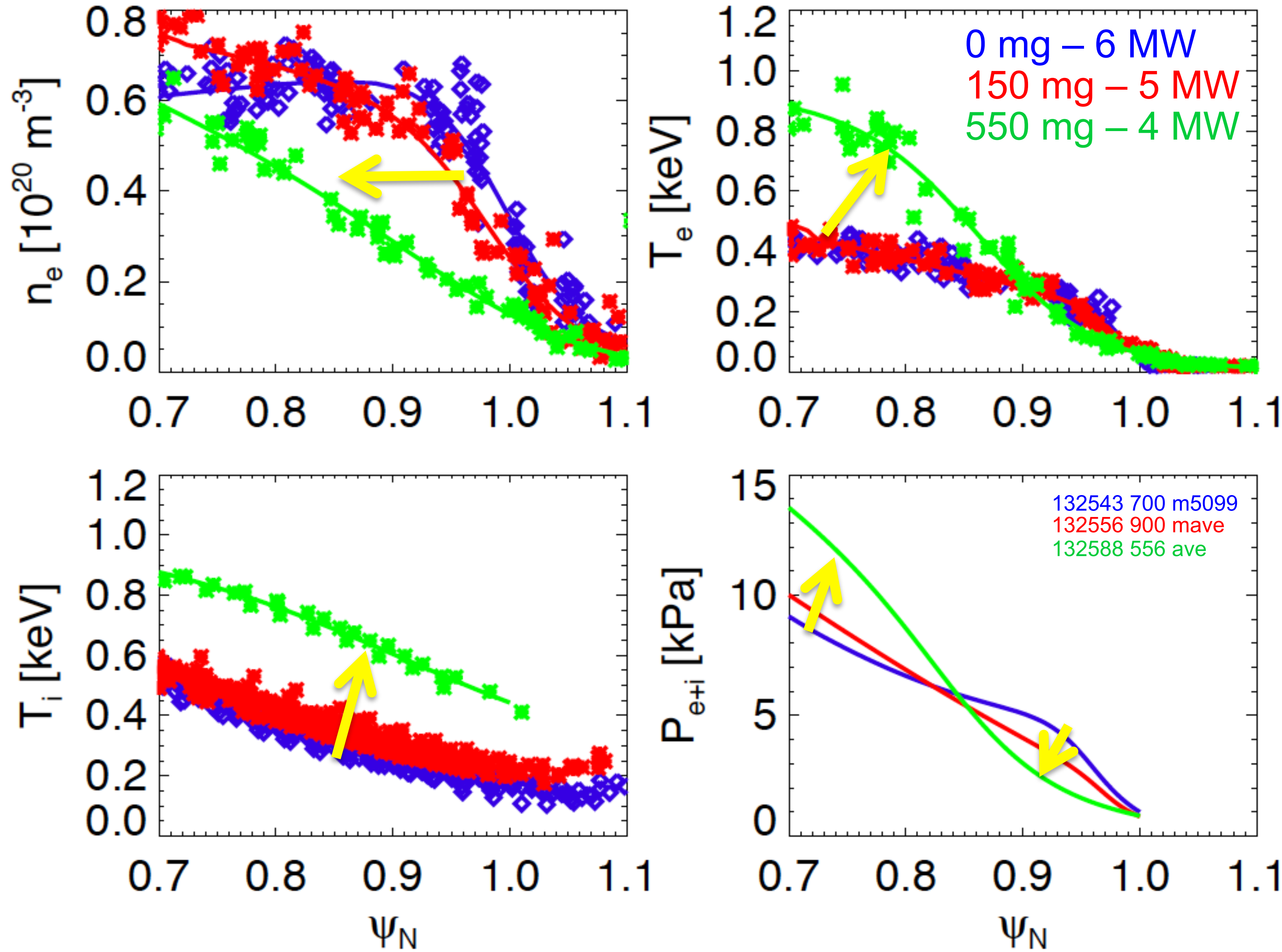


- Transition from high to low recycling in lower (active) divertor occurred at lower evaporation levels in highly shaped discharges than weakly shaped ones
- Comparable trends in upper divertor recycling

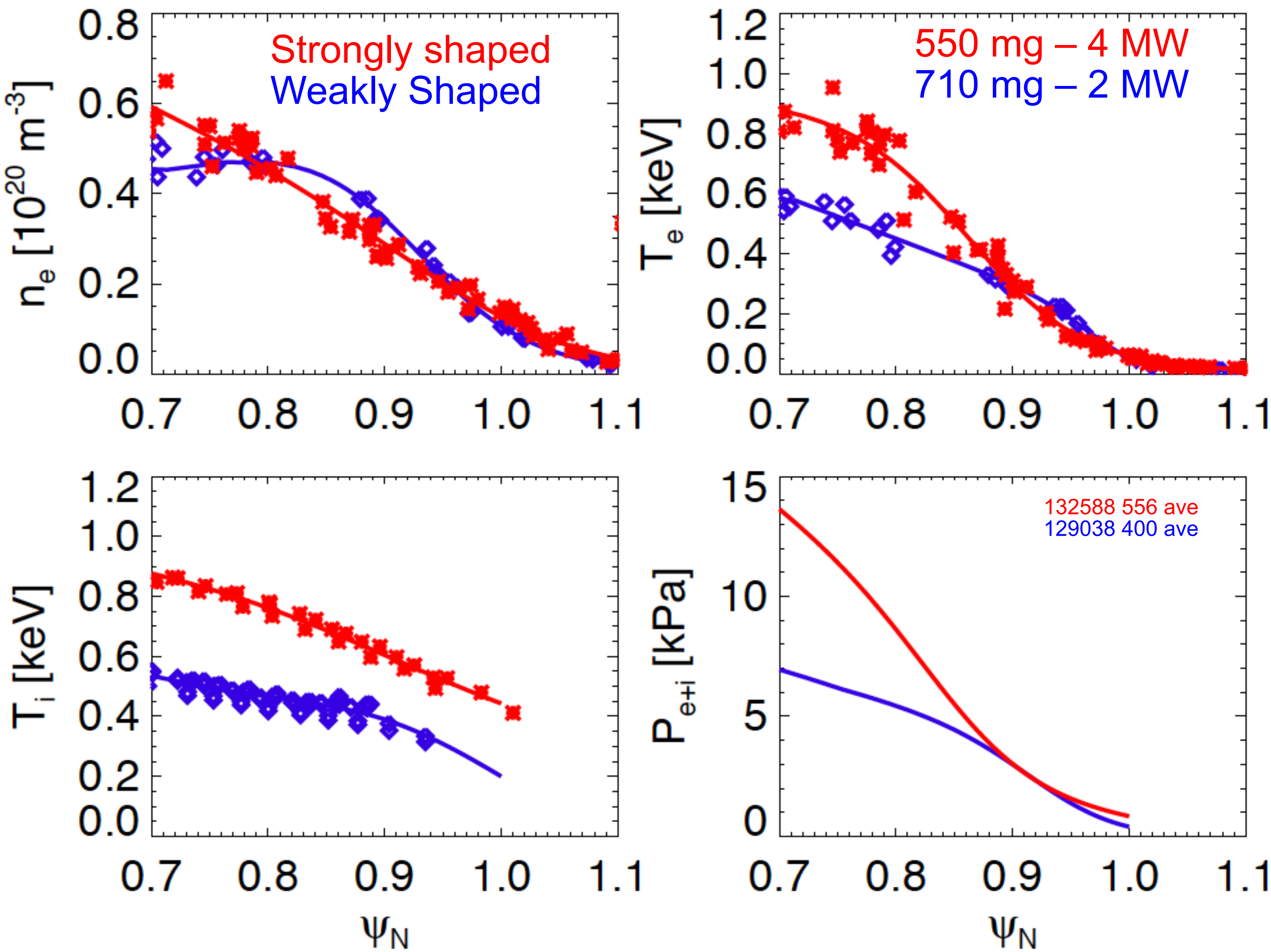
D_α and neutral pressure decreased, and H97L increased with increasing pre-discharge lithium evaporation in all data



Edge profiles change markedly with increasing lithium in strongly shaped discharges, as in weakly shaped ones



Density profile modification similar in strongly and weakly shaped discharges

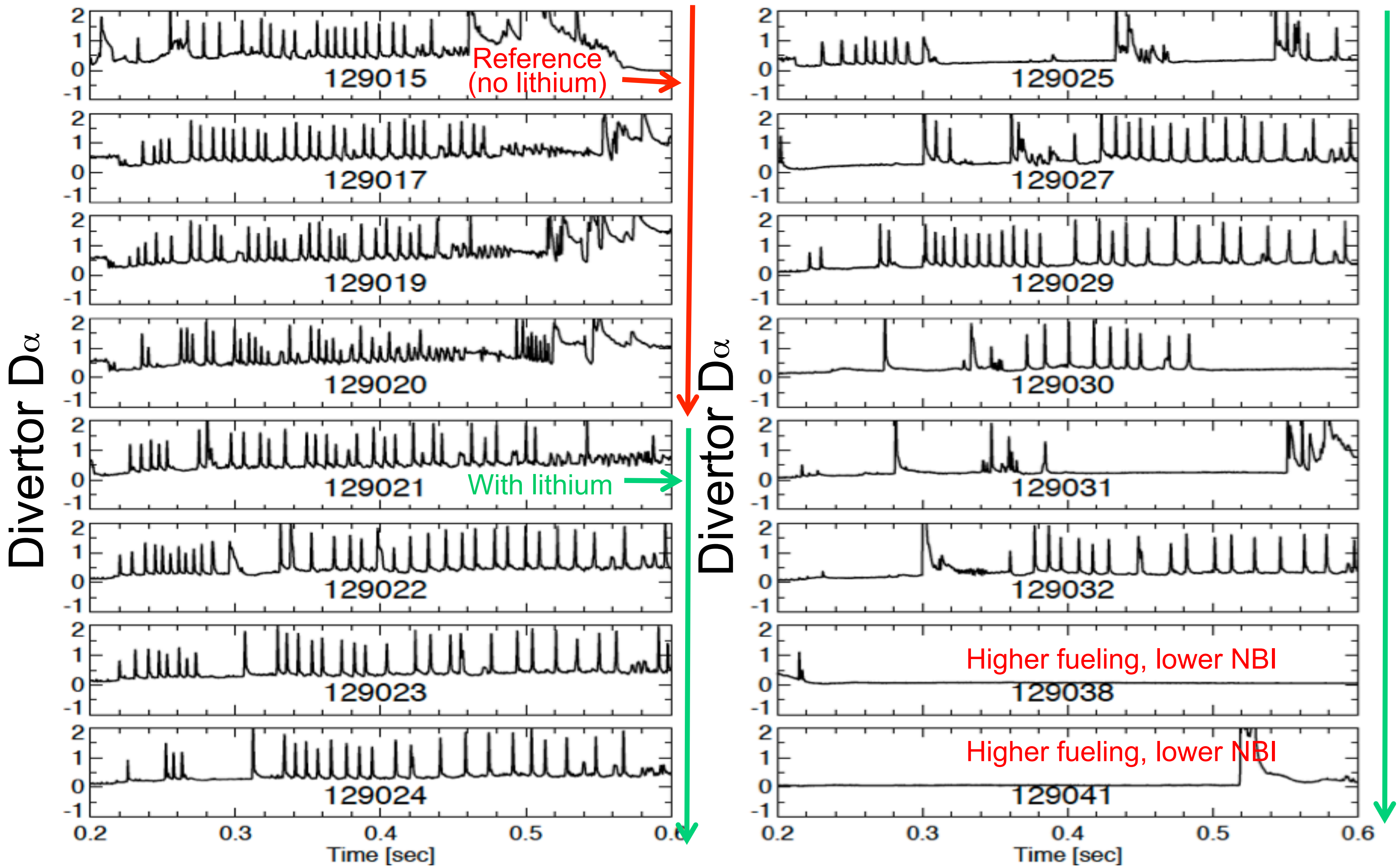


Trend of improving discharge performance with increasing lithium observed in highly shaped plasmas

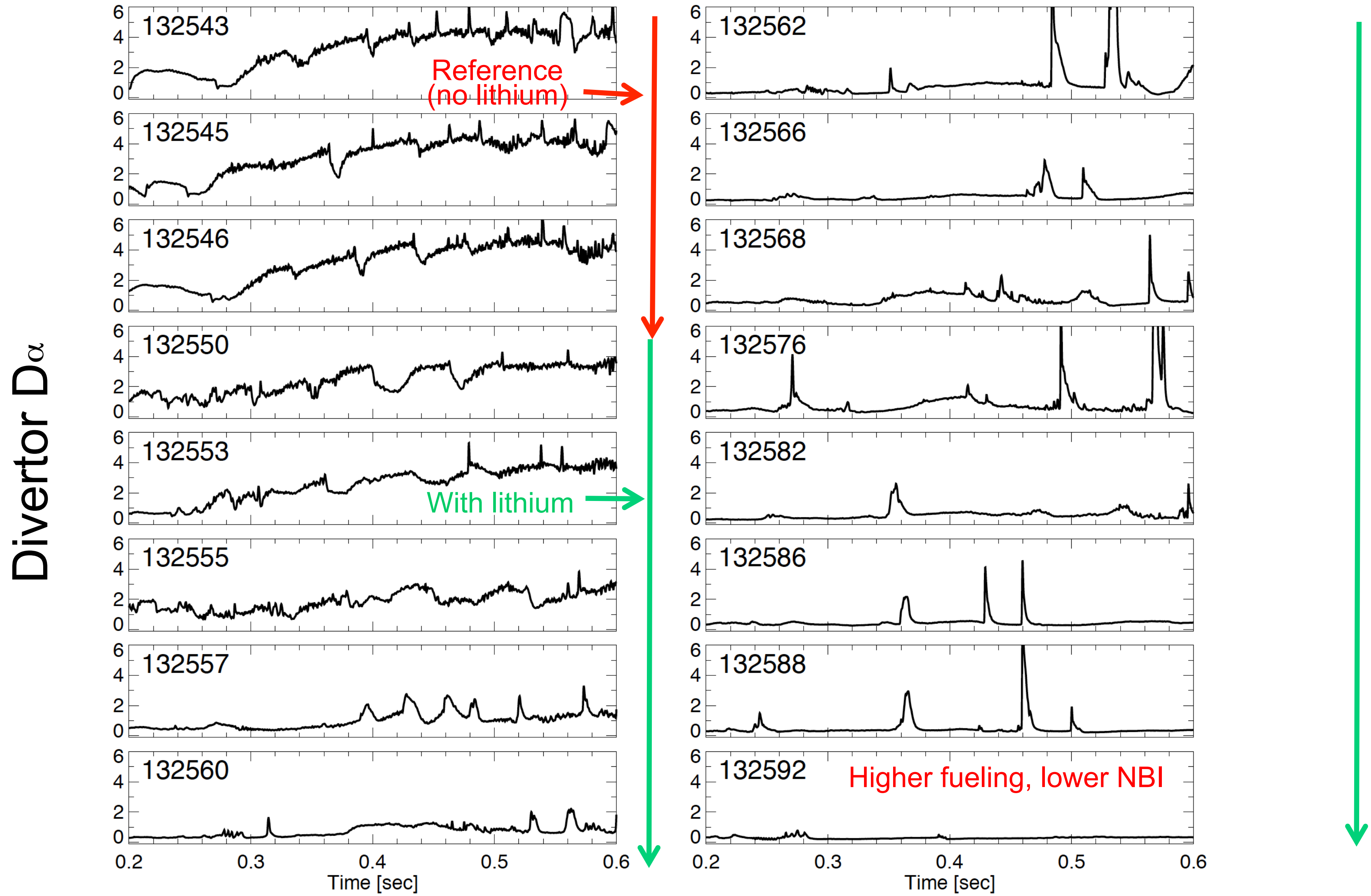
- Recycling and neutral pressure decreased with increasing lithium
- Energy confinement increased and edge stability improved with increasing lithium
  - Discharge improvement was not unilateral; more ELMs and other transients, less reproducibility than in scans in weakly shaped plasmas
- Detailed transport analysis (TRANSP), pedestal profile and stability analysis in progress
  - Role of ν^* being assessed
- To do: compare with data from Liquid Lithium Divertor

BACKUP

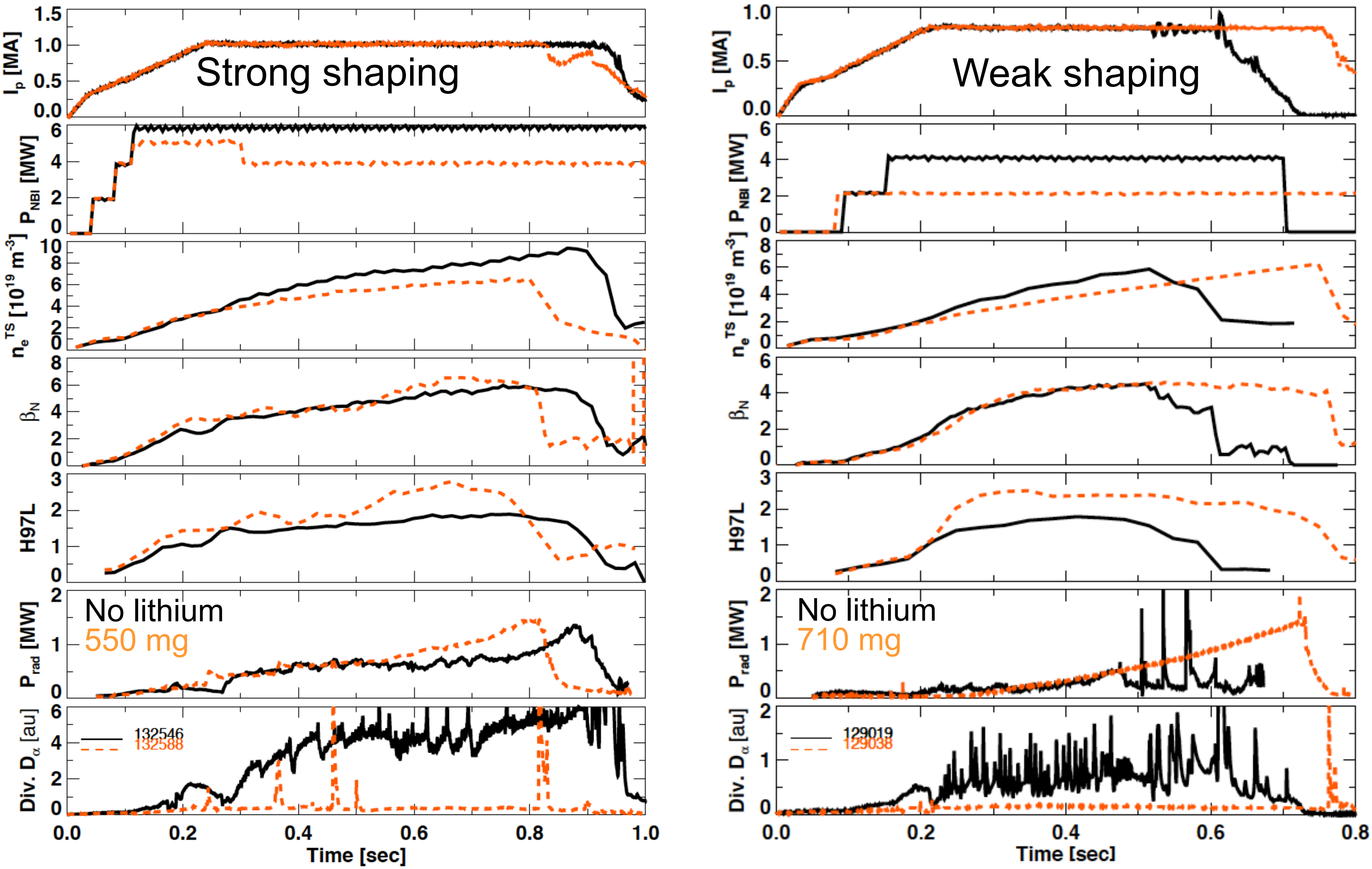
ELMs eliminated gradually during original experiment



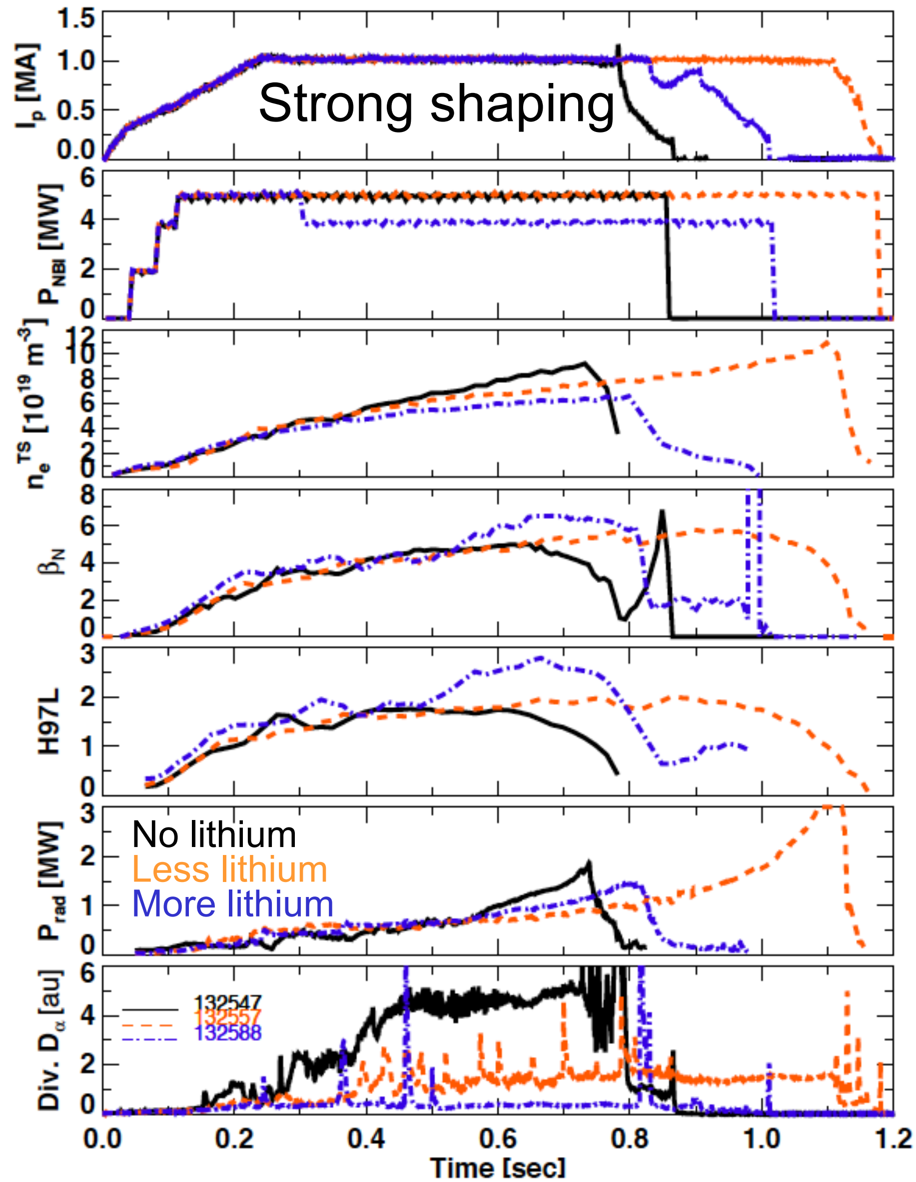
ELM evolution similar but ELMs never quite completely eliminated during new experiment



Lithium reduced recycling and improved confinement of both strongly and weakly shaped discharges

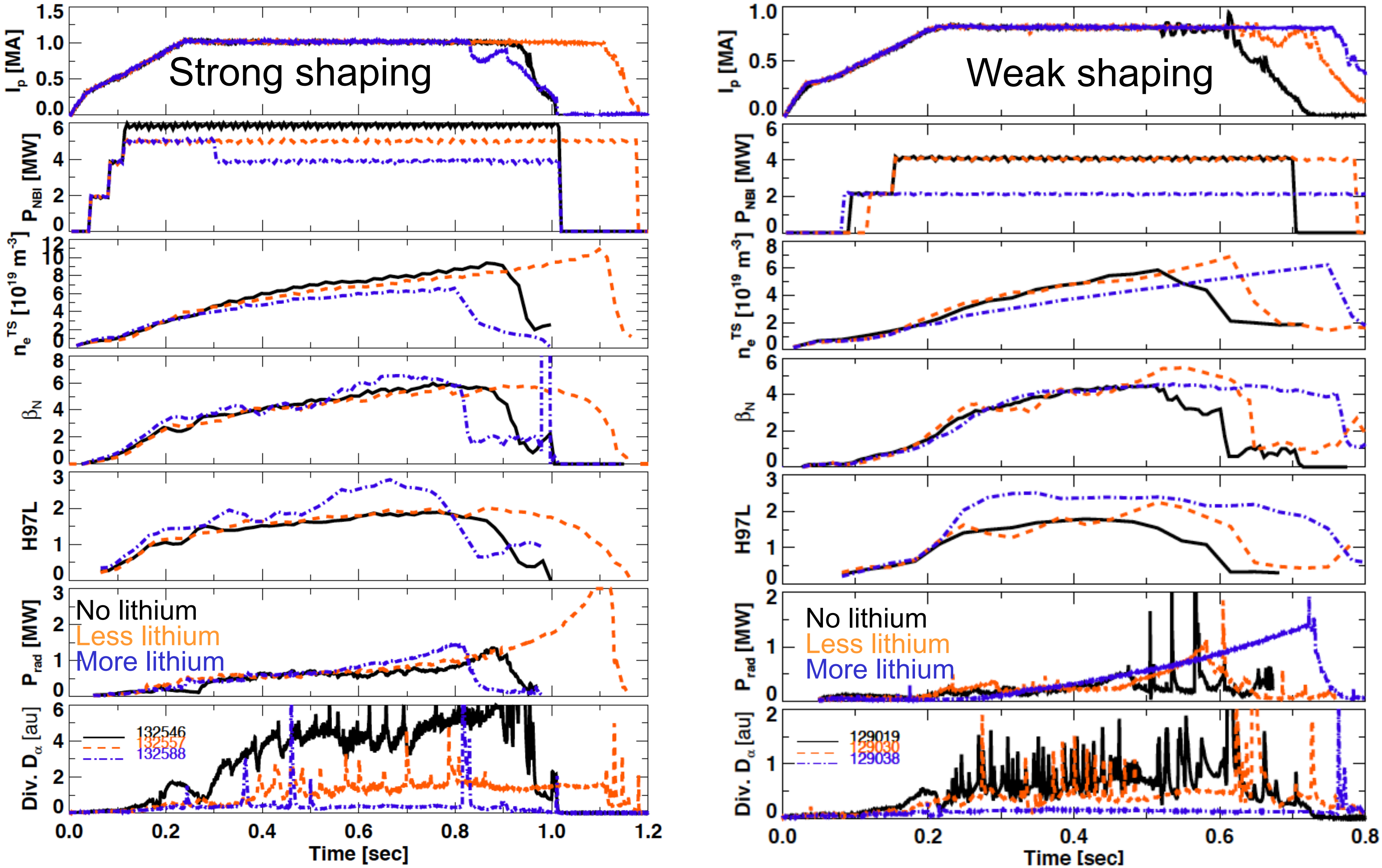


Similar effects on discharges observed with weak and strong shaping

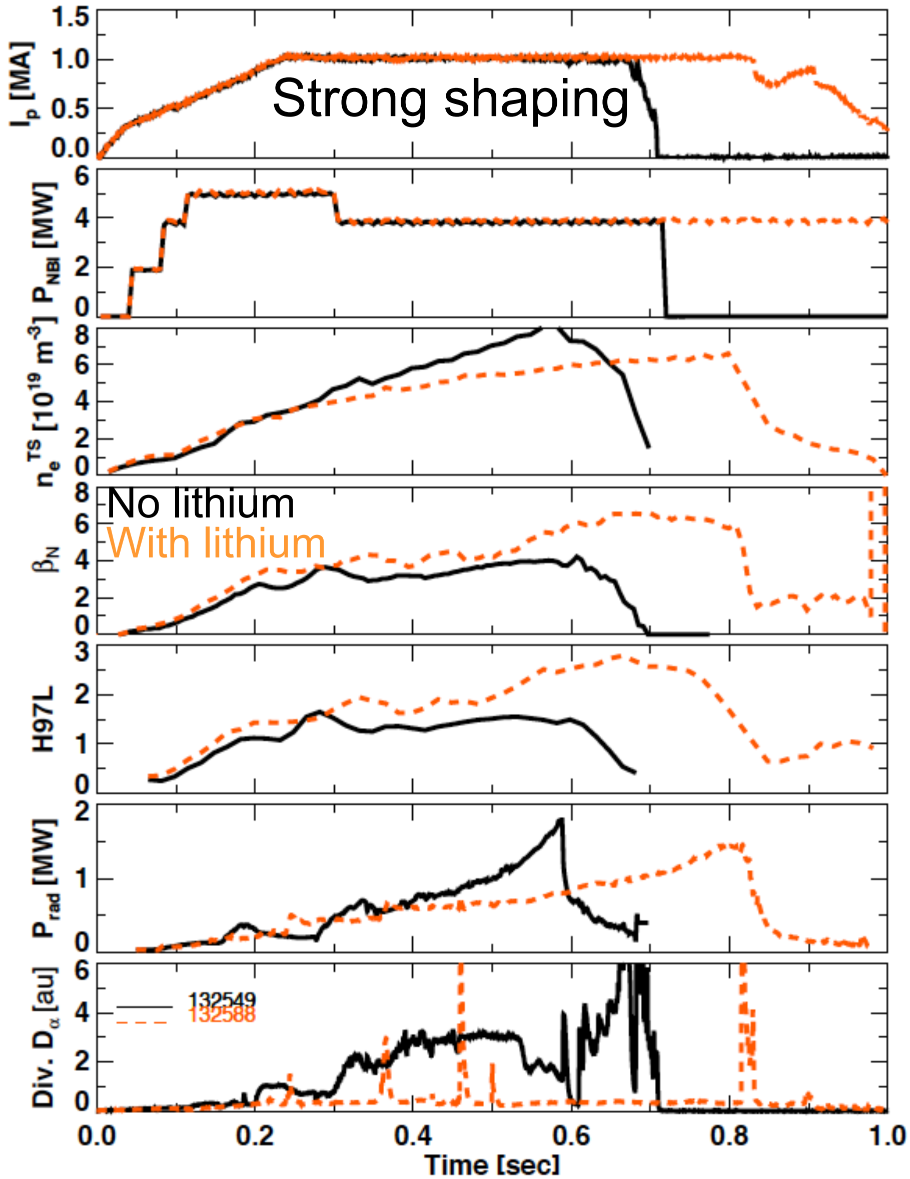


- Duration extended
- Same and lower P_{NBI}
- Reduced dN/dt
- Higher stored energy
- Higher confinement
- Increasing P_{rad}
- Reduced recycling, long ELM-free phases

Similar effects on discharges observed with weak and strong shaping

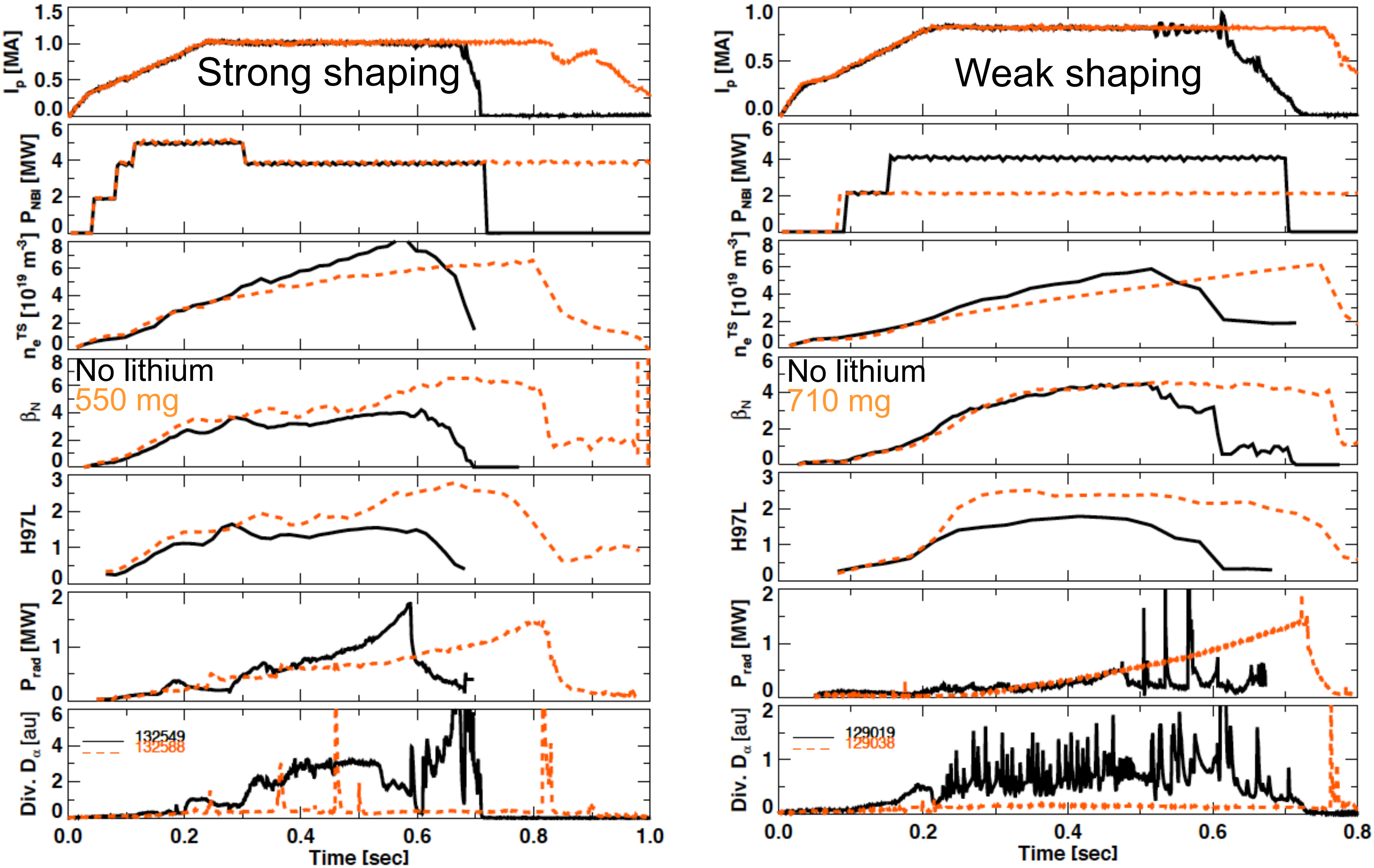


Lithium improved performance of strongly shaped discharges, similar to weakly shaped ones

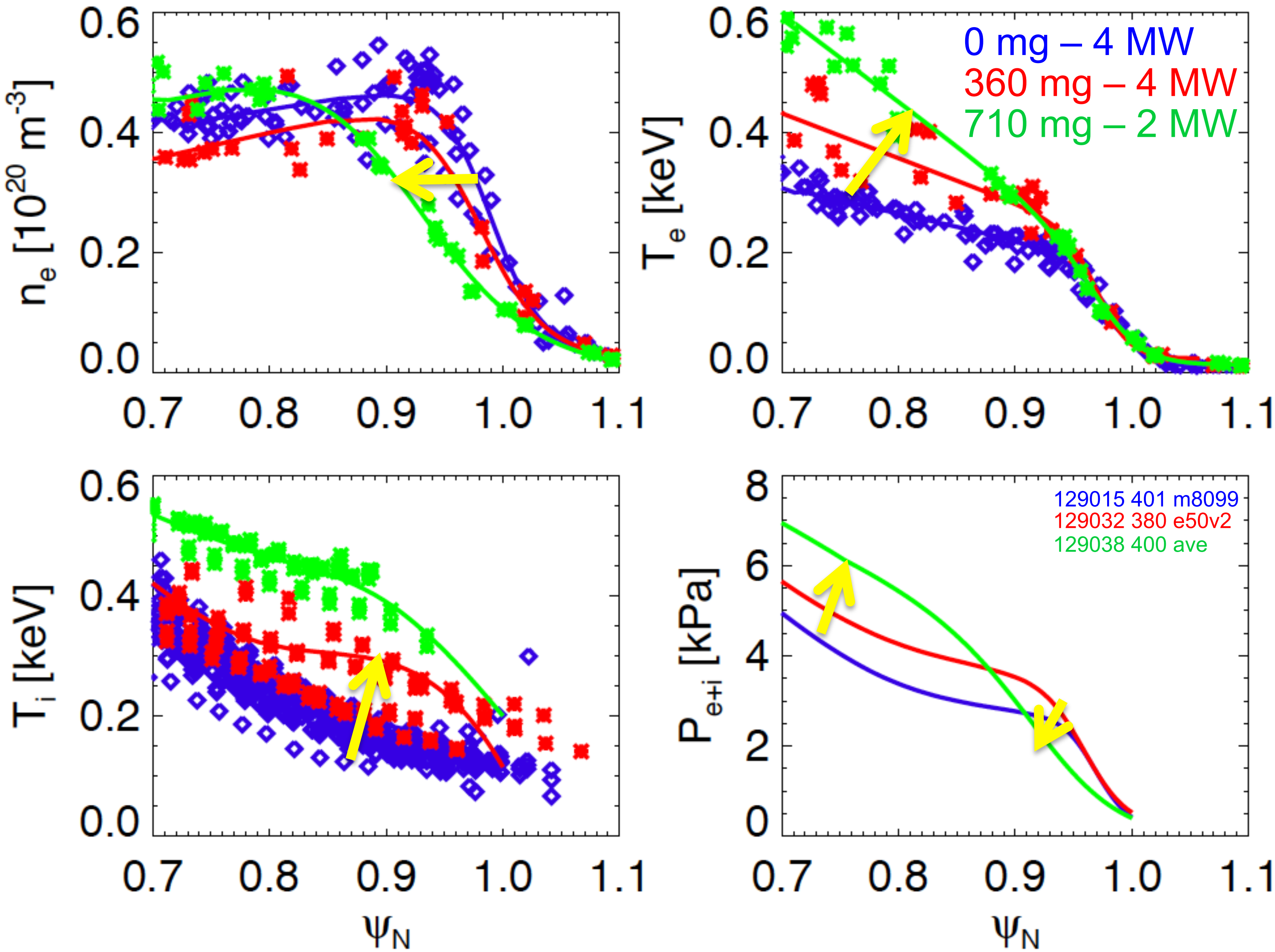


- Duration extended
- Same P_{NBI}
- Reduced dN/dt
- Higher stored energy
- Higher confinement
- Increasing P_{rad}
- Reduced recycling, long ELM-free phases

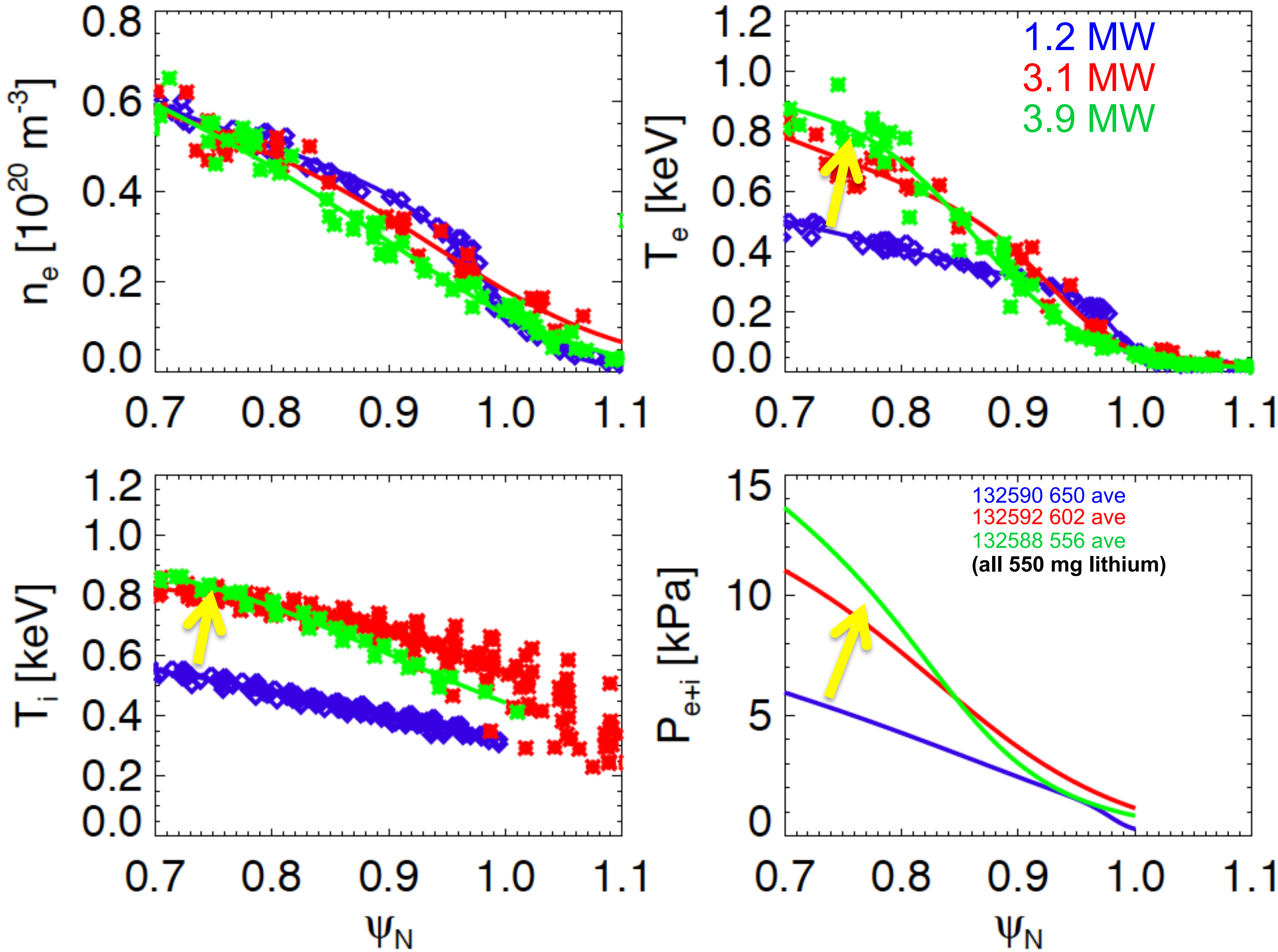
Similar effects on discharges observed with strong and weak shaping



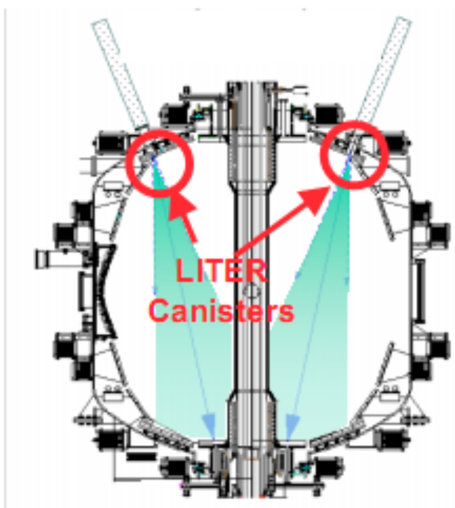
Edge profiles change markedly with increasing lithium in weakly shaped discharges

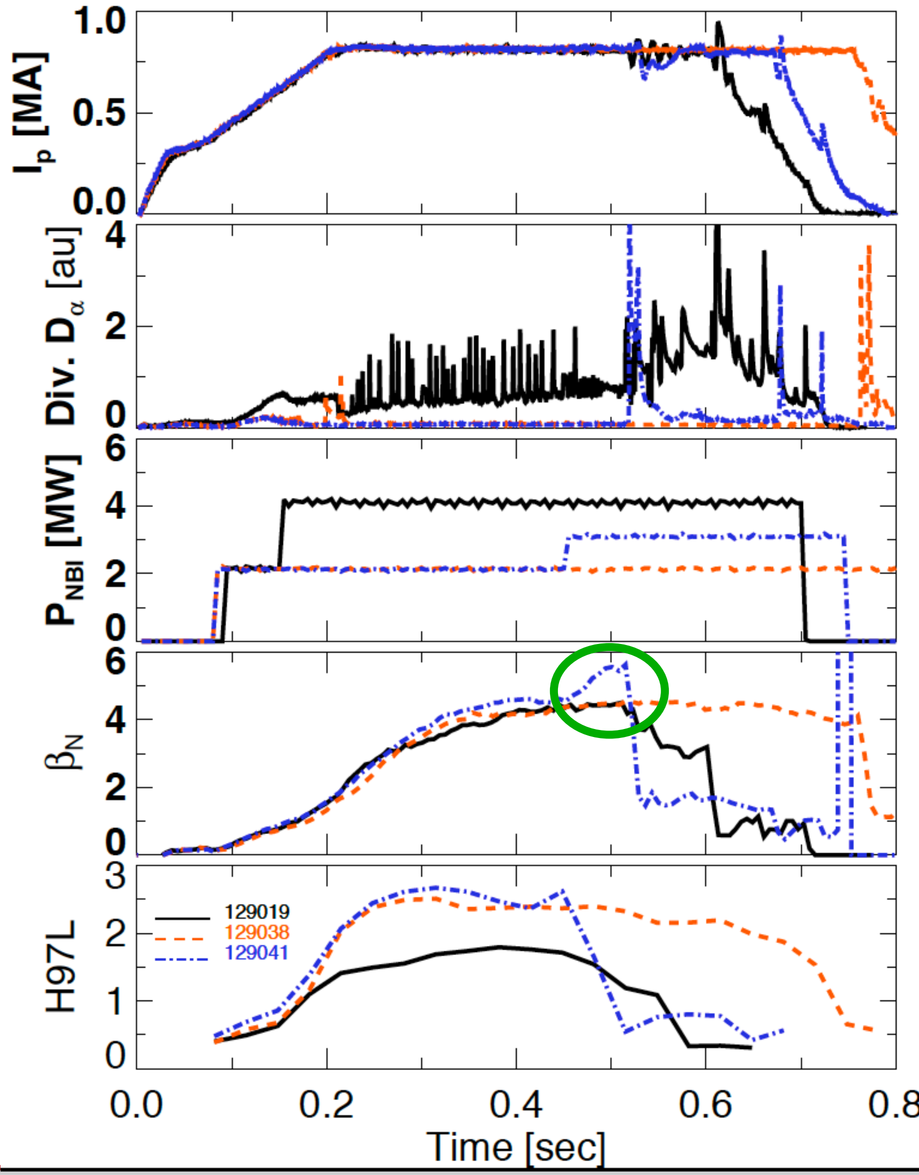


At high lithium deposition, pressure and stored energy increase with P_{NBI} in strongly shaped discharges



Edge stability limits pushed beyond global stability limits with lithium coatings in NSTX

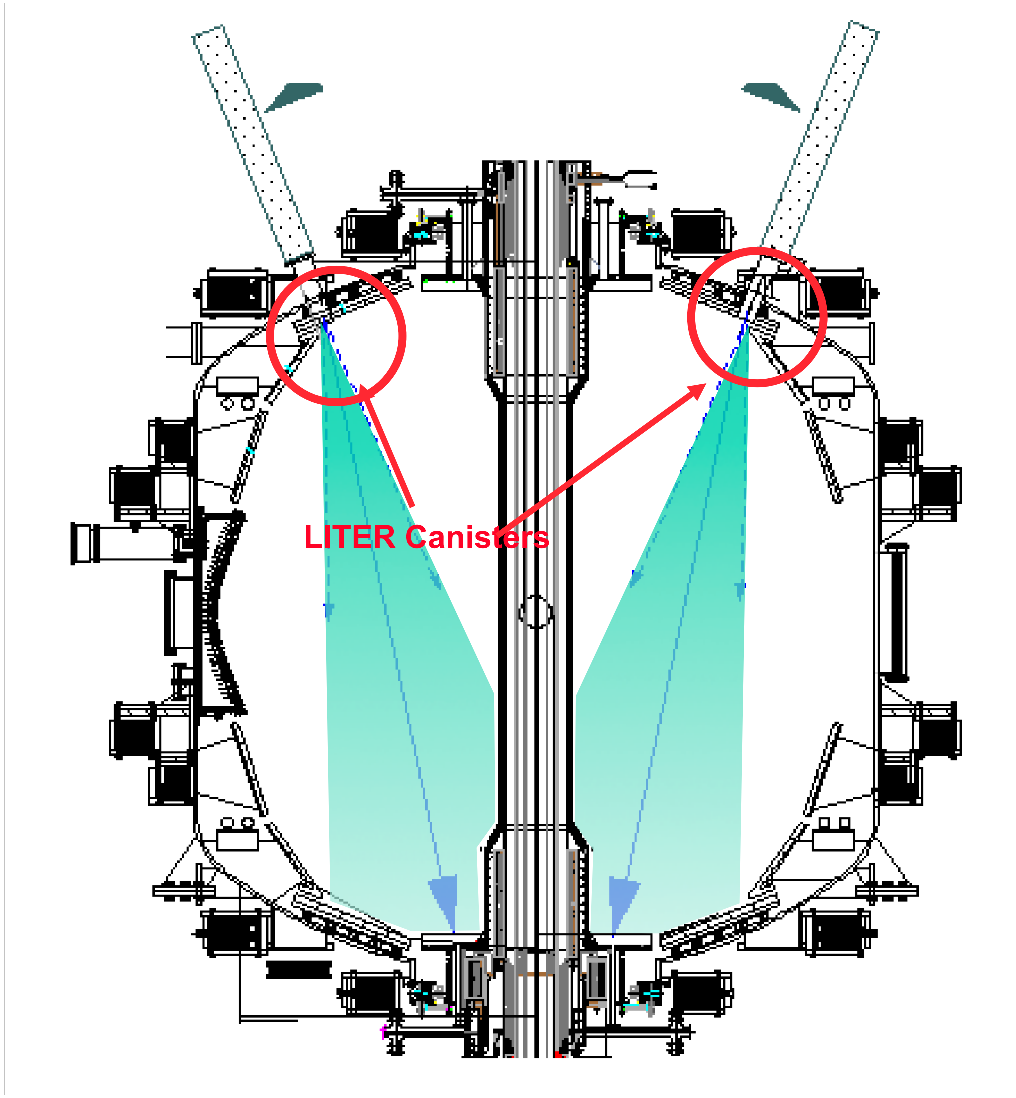


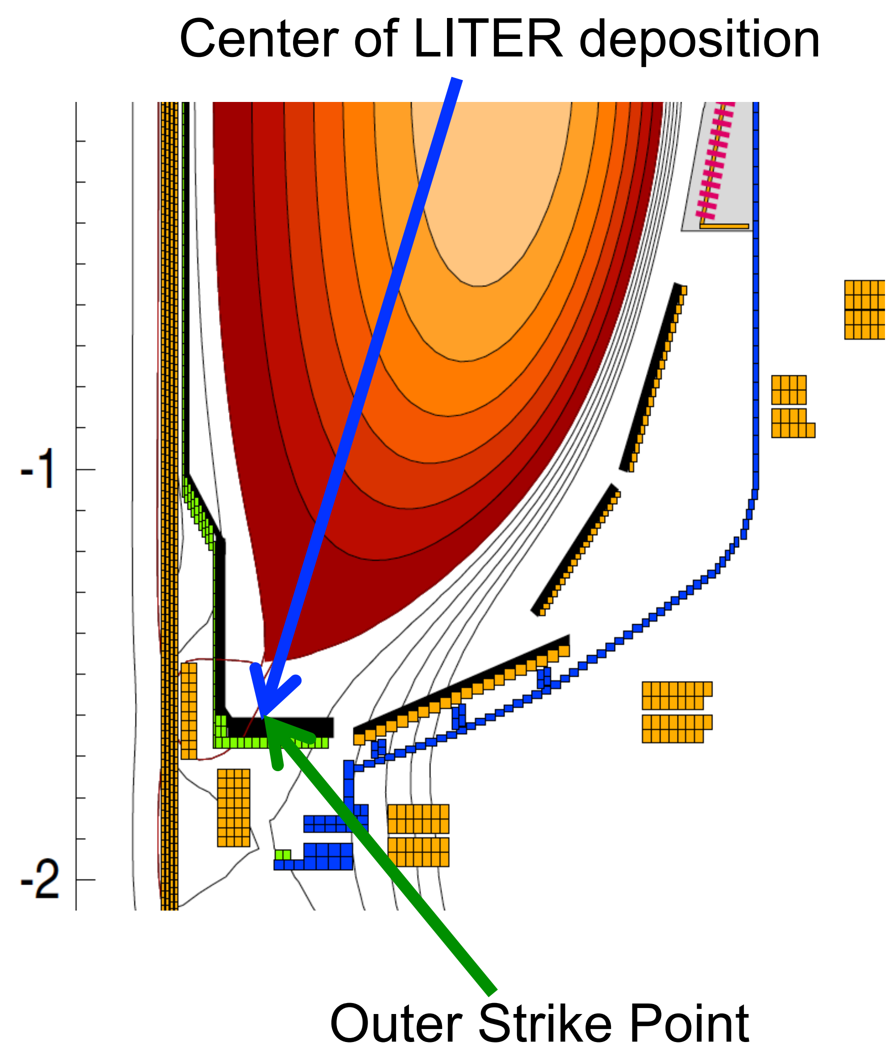


- Without Li, With Li, With Li
- ELM-free, reduced divertor recycling
- Power scan to identify β limit
- Core β limit observed, but no ELMs

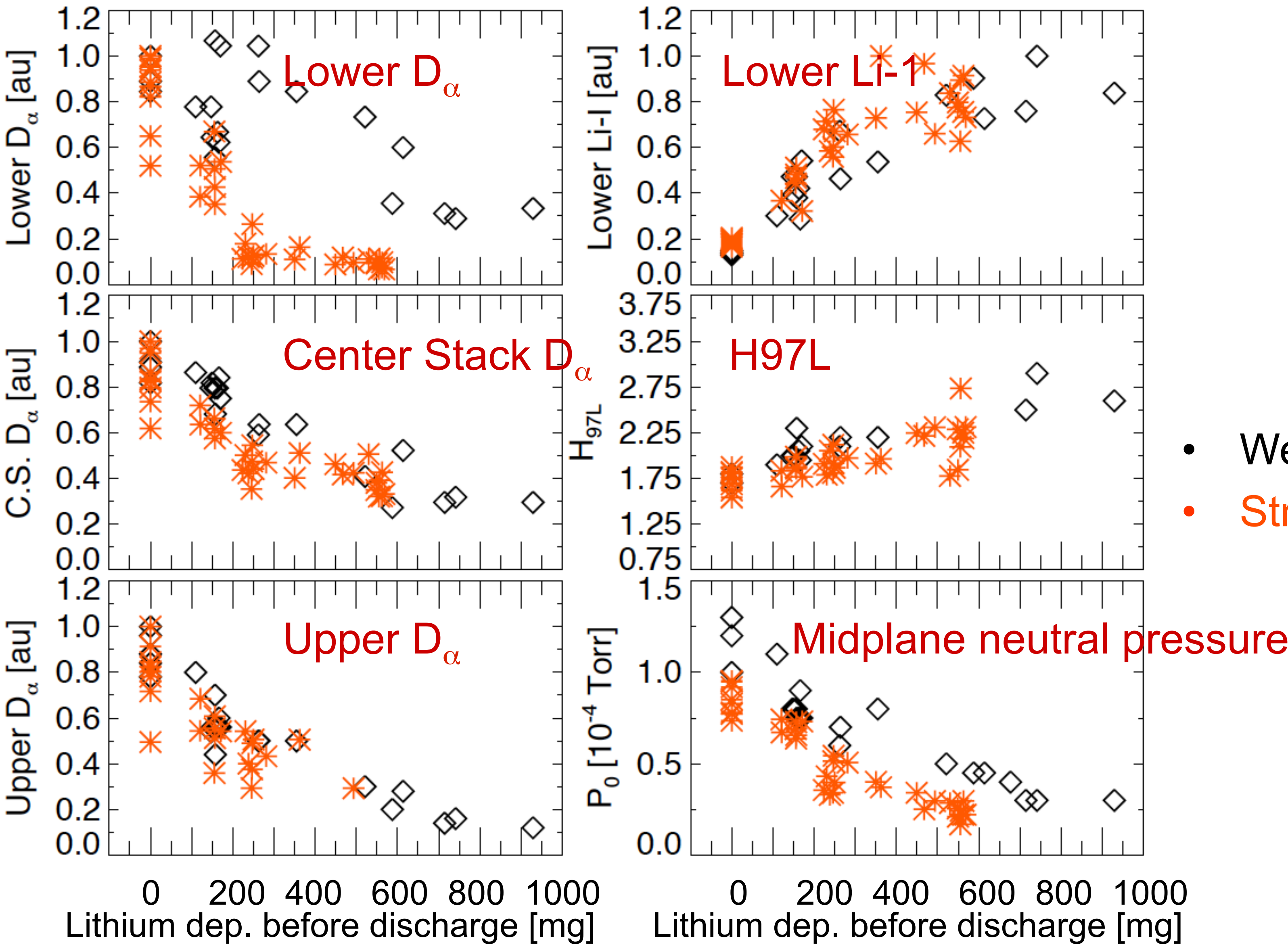
D. Mansfield, JNM 09
R. Maingi, PRL 09

New data taken in highly shaped plasmas has higher LITER deposition near outer strike point



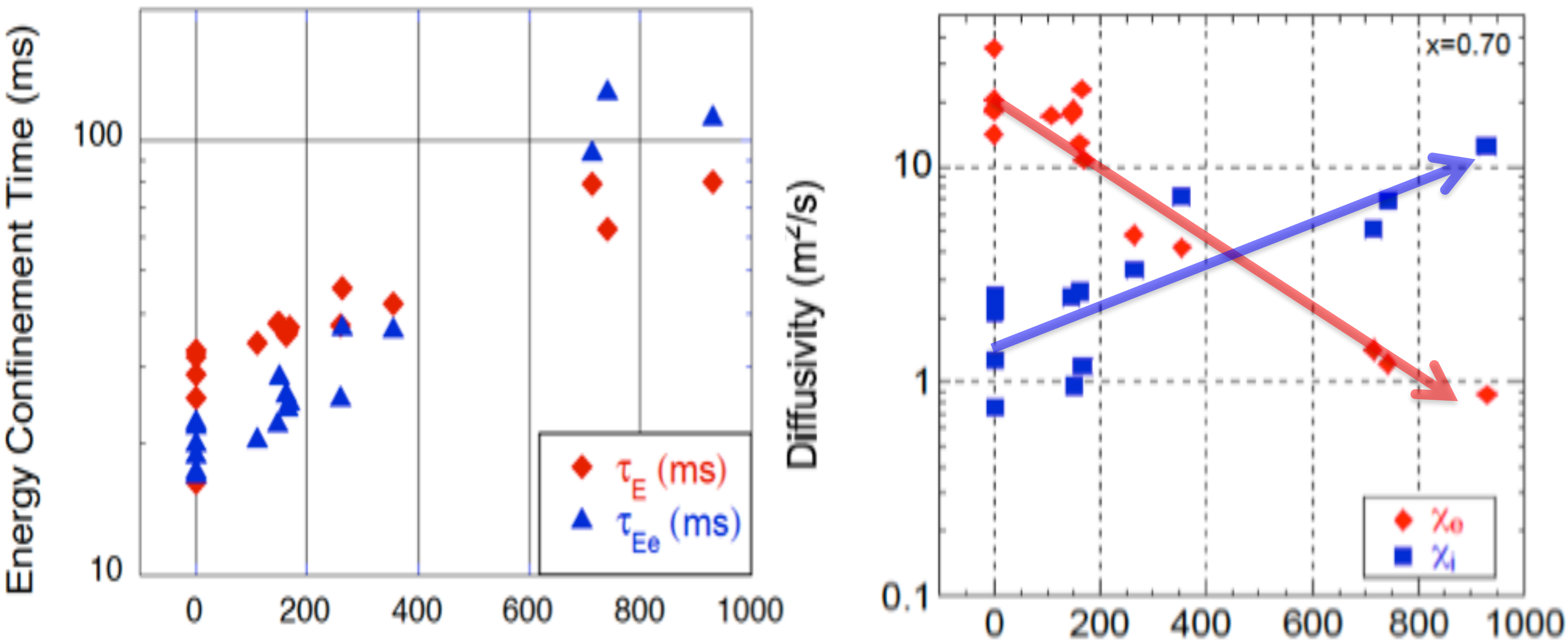


Neutral pressure decreased with increasing lithium; Li-I light and H_{H97L} increased, but H97L trend may be weaker



- Weak shaping
- Strong shaping

Energy confinement increased and edge electron transport decreased with pre-discharge lithium evaporation



Pre-discharge lithium deposition (mg)

- Edge ion transport increased

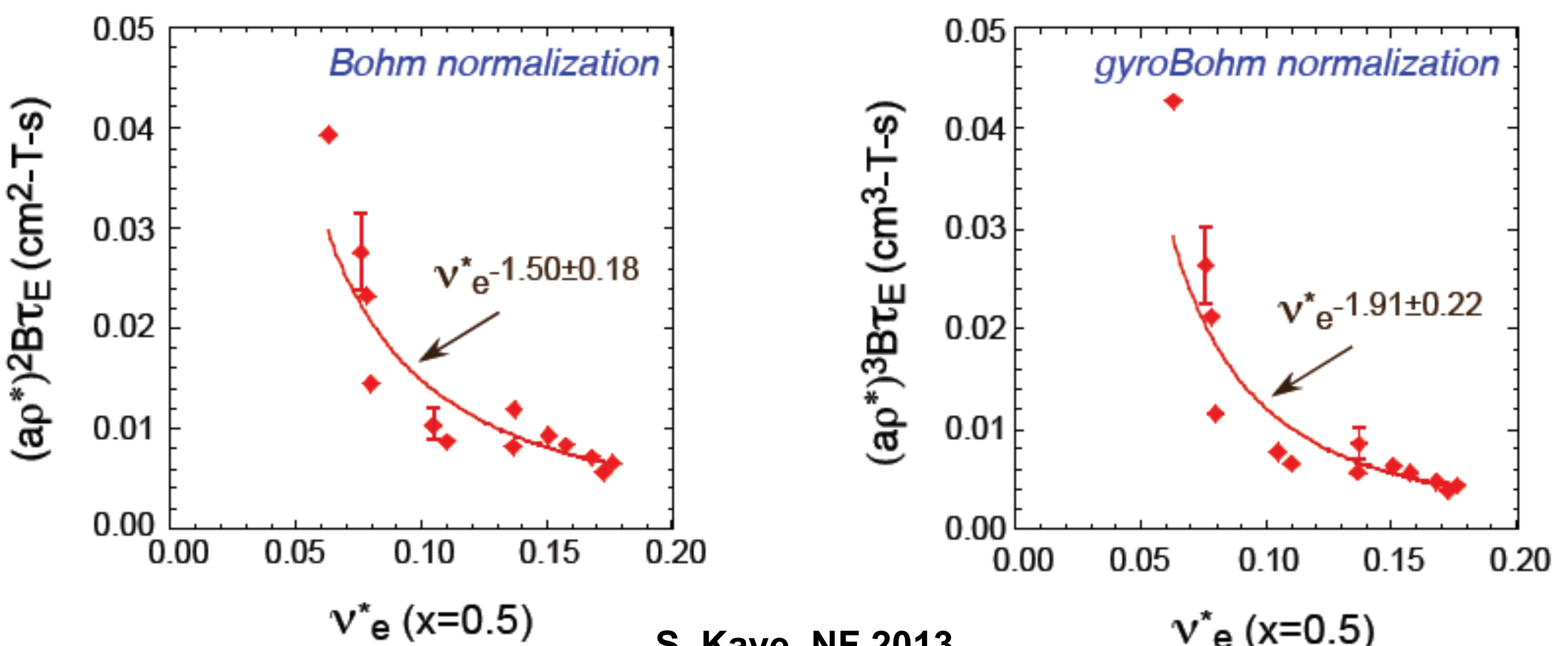
R. Maingi, PRL 2011, NF 2012; S. Kaye, NF 2013

TRANSP

Dependence on ν^* even stronger when ρ^* variations considered

- *Express confinement scaling in terms of dimensionless parameters $\Omega\tau_E = B\tau_E = \rho^{*\alpha} f(\nu, \beta, T_e/T_i, \kappa, q, \ldots\ldots.)$ where $\alpha = -2$ for Bohm and $\alpha = -3$ for gyroBohm scaling*
  - *NSTX HeGDC+B discharges found to be consistent with gyroBohm (Kaye, 2006)*
- *For the Li scan, B, q, <β>, κ, a … constant for all discharges*

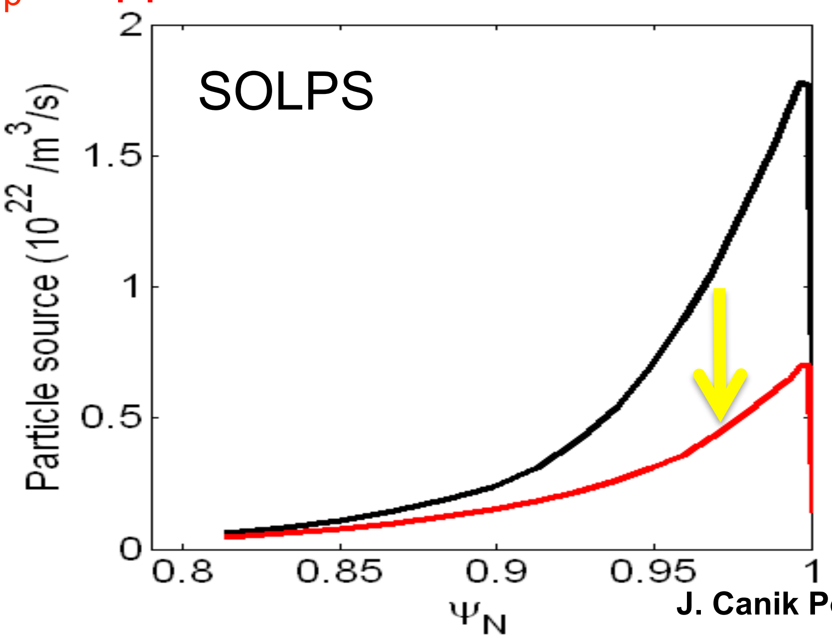
Normalize τ_E further by $\rho^{*\alpha}$: test both Bohm and gyroBohm



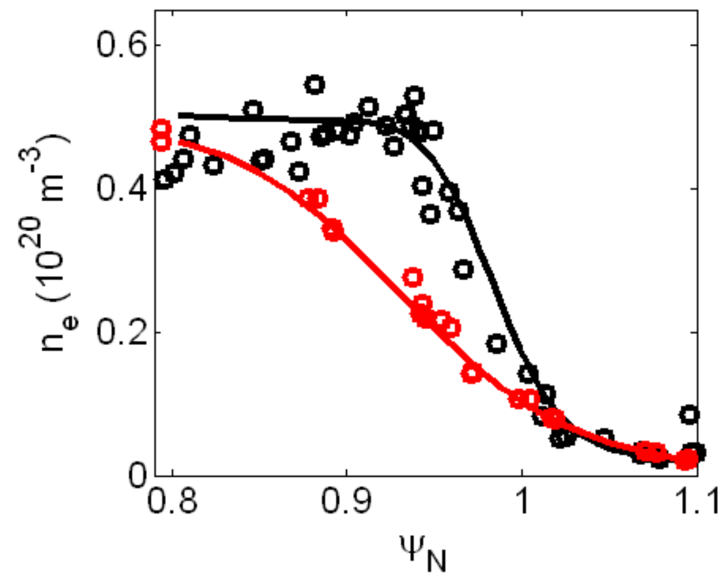
S. Kaye, NF 2013

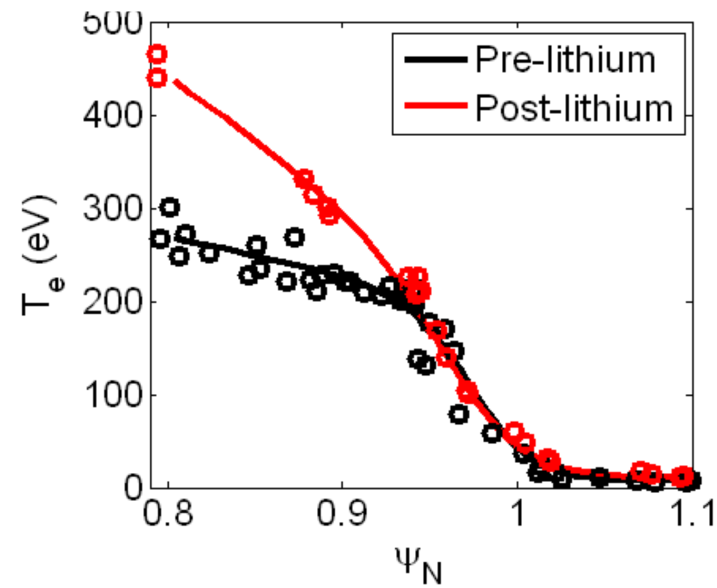
SOLPS interpretive simulations indicate particle fueling source from recycling was reduced with lithium

- Target recycling coefficient varied to match peak divertor D_α
- Separatrix position adjusted as needed to match divertor peak heat flux
- Radial profile of D_{eff}, χ_e^{eff}, χ_i^{eff} varied to match midplane n_e, T_e, T_i, for the computed recycling source profile
- R_p dropped from 0.98 to 0.9 with lithium



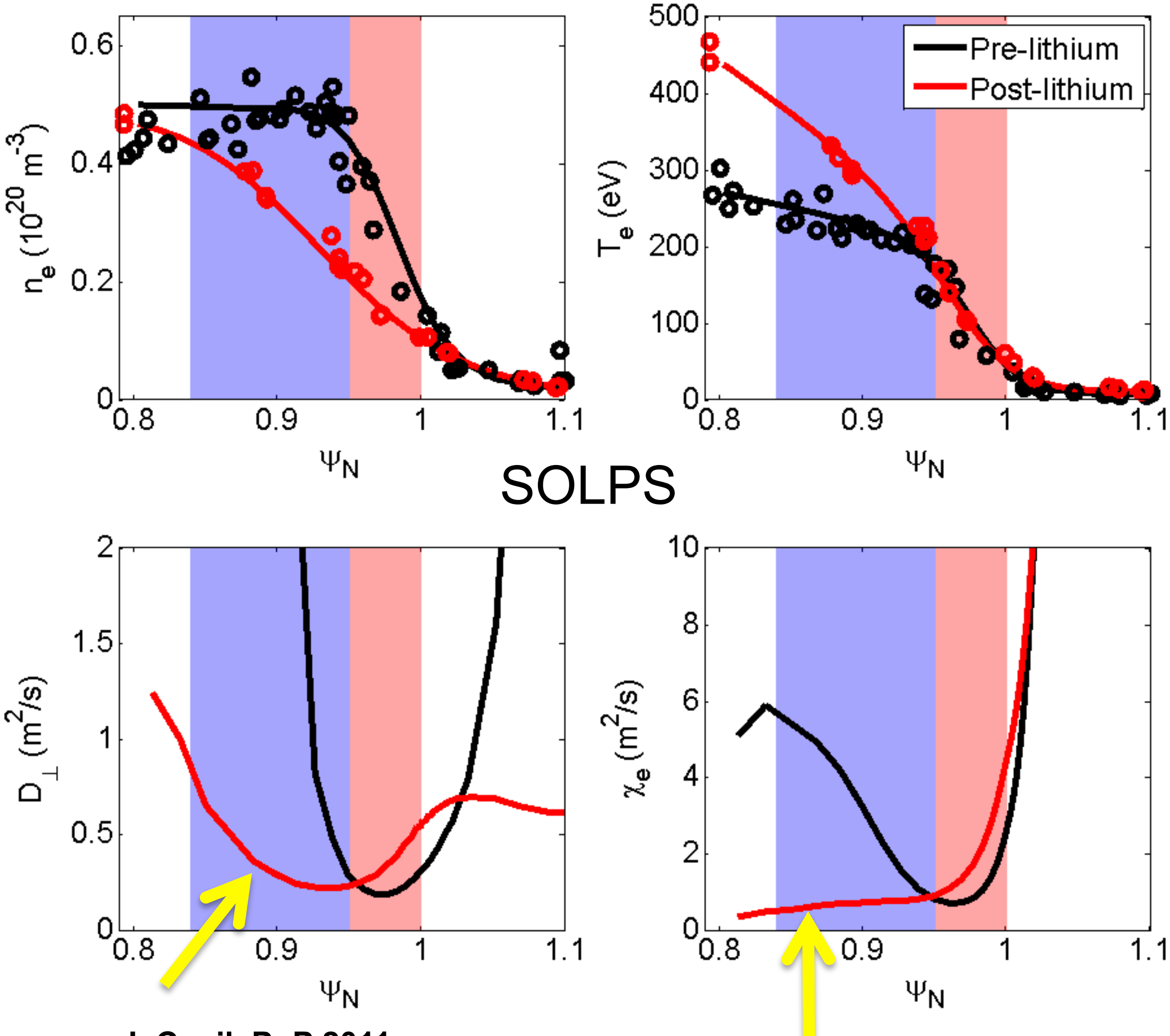
J. Canik PoP 2011





Recycling and edge transport changes interpreted with SOLPS simulations

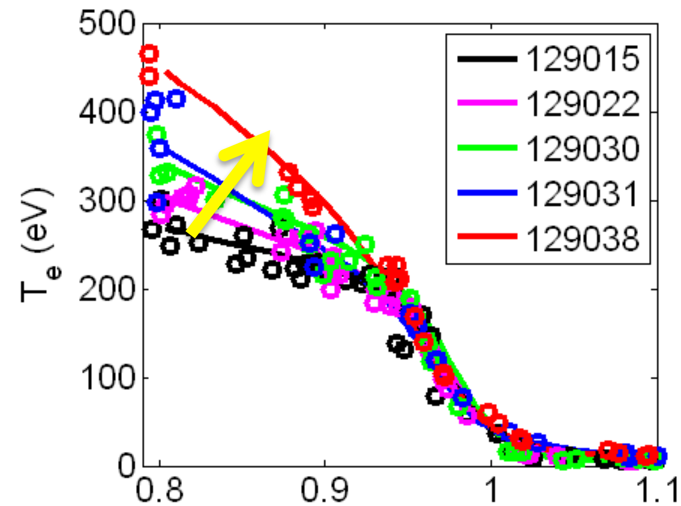
- Pre-lithium case shows typical barrier region inside separatrix
- Change in n_e profile with lithium from $0.95<\psi_N<1$ consistent with drop in fueling at ~ constant transport
- Spatial region of low transport expanded with lithium
  - Low $D_\perp$, χ_e persist to inner boundary of simulation (ψ_N~0.8)

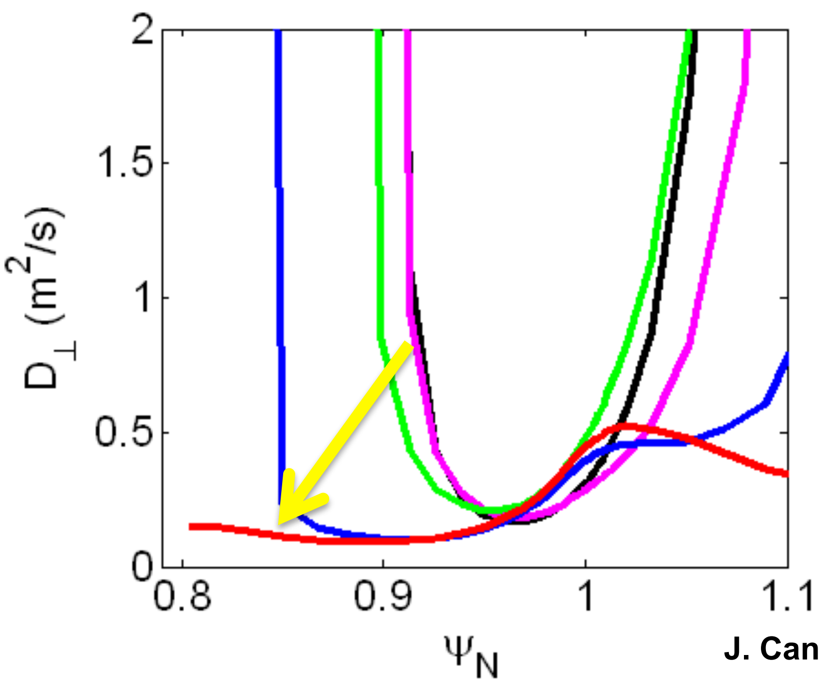


J. Canik PoP 2011

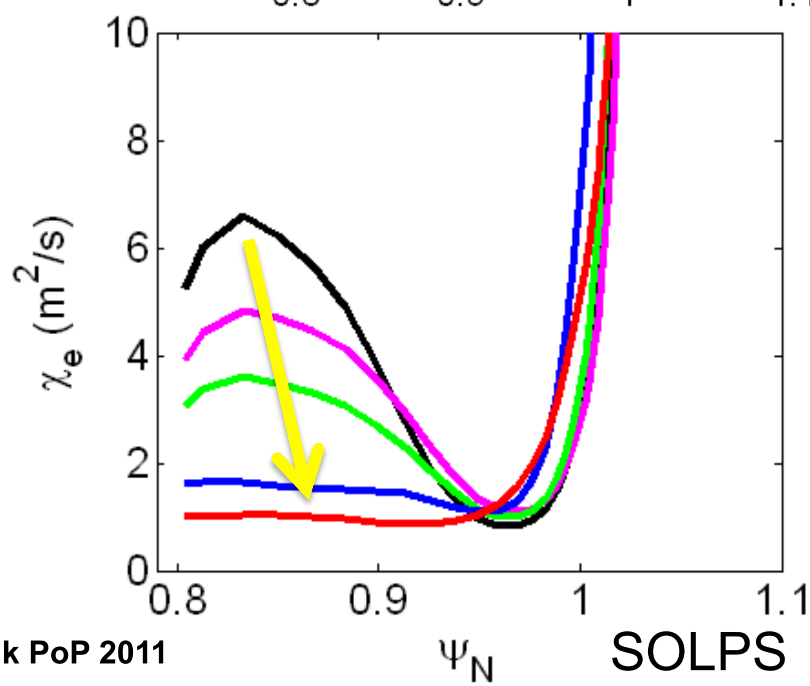
Spatial extent of low D, χ_e region expanded continuously with increasing pre-discharge lithium

- Several shots analyzed with SOLPS with increasing lithium (direction of arrow)
- T_e gradient clamped in last 5% of ψ_N, but increased from ψ_N=0.8-0.95
- First three discharges were ELMy, last two ELM-free



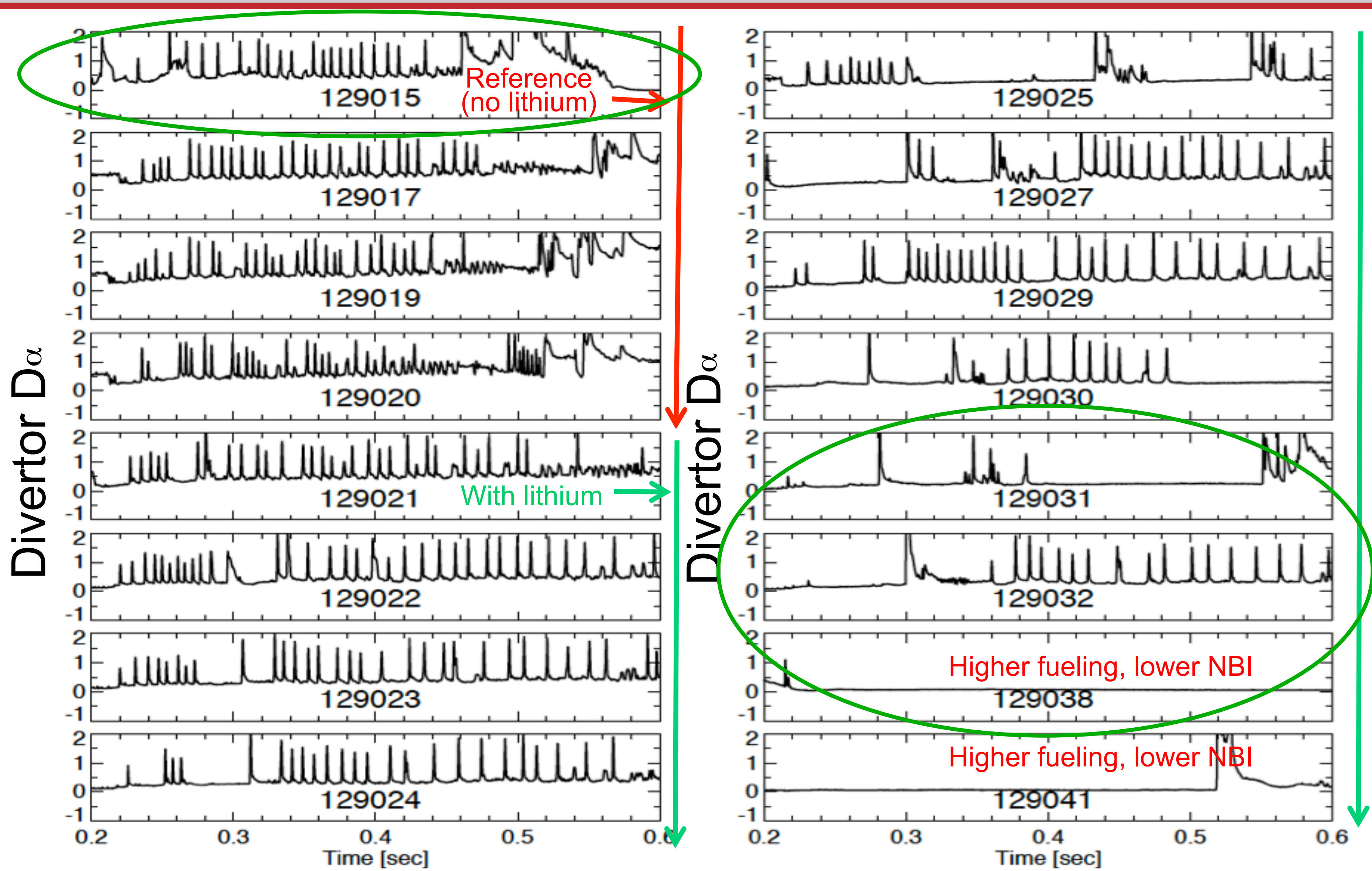


J. Canik PoP 2011

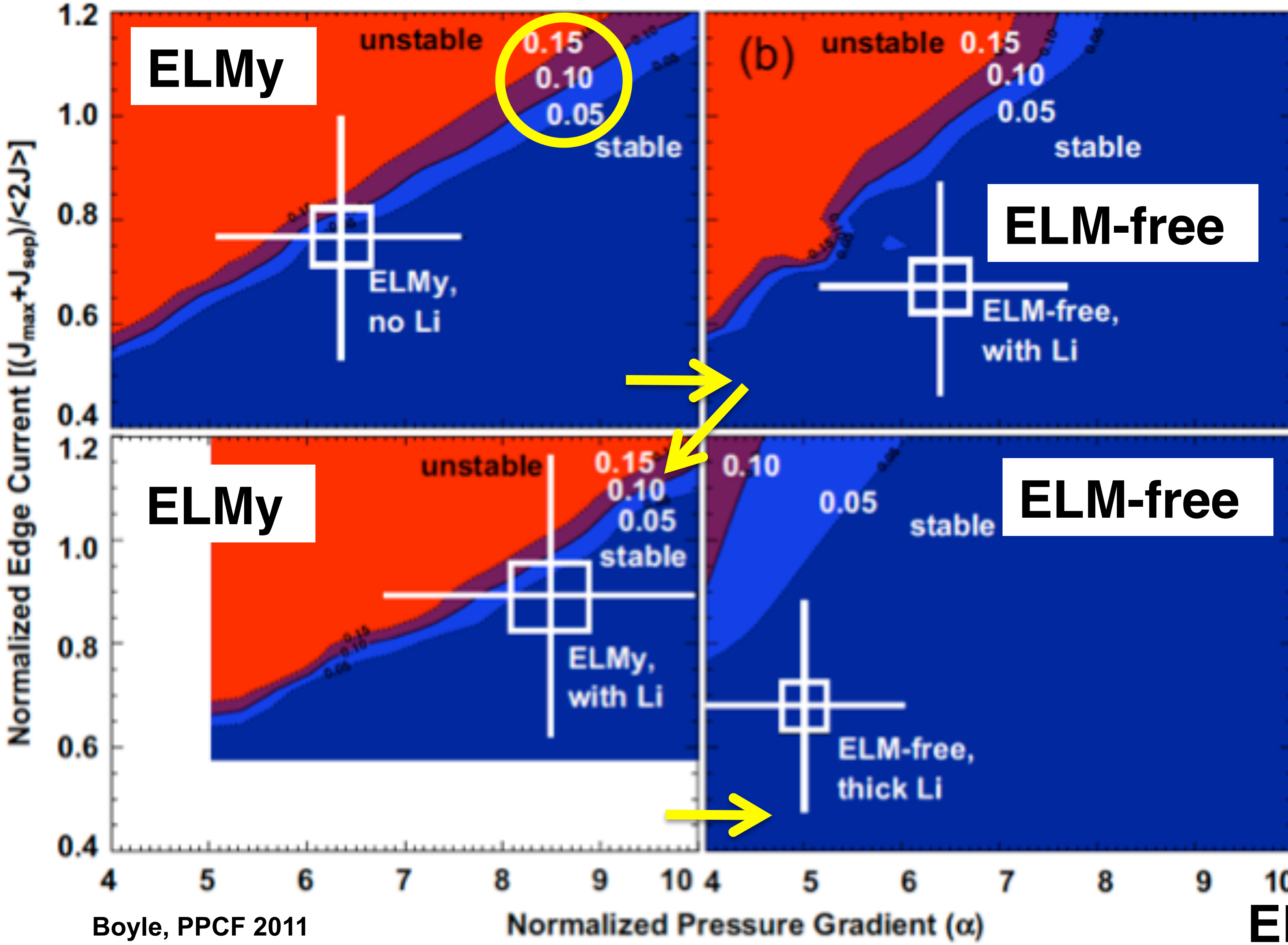


SOLPS

ELM elimination was not quite monotonic



ELMy discharges closer to kink/peeling stability boundary than ELM-free ones but ideal growth rates low: why instabilities not stabilized by diamagnetic flow?



Boyle, PPCF 2011

ELITE

What is the role of lithium?
To reduce recycling and associated fueling

ψ_N from 0.95-1 (recycling region)

Li coatings reduce recycling and core fueling (SOLPS)

→

n_e and ∇n_e reduced
∇T_e fixed

χ_e increased
ETG? (GS2)

→

n_e, P_e gradient reduced

P_i gradient unchanged

→

J_{bs}, $J_{||}$ reduced - stabilizing (ELITE)

ψ_N from 0.8-0.94

D_{eff} reduced, most in ELM-free (SOLPS)

→

n_e and ∇n_e
T_e and ∇T_e
increased

χ_e reduced strongly – μT stable? (GS2)

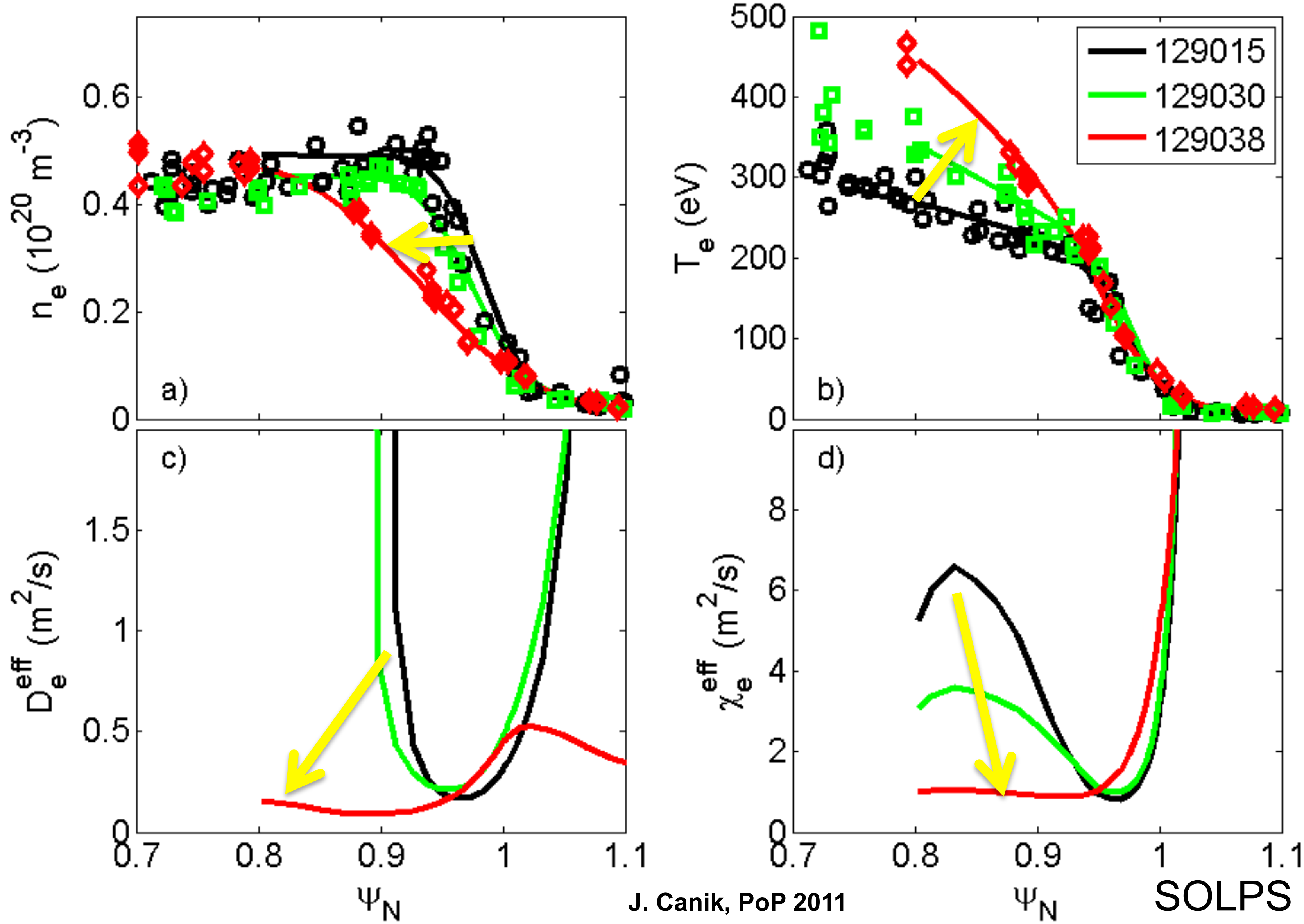
→

Edge P_e follows n_e and T_e; peak P' shifts farther from separatrix

→

J_{bs}, $J_{||}$ increased but far from separatrix; improves stability to kink/peeling modes (ELITE)

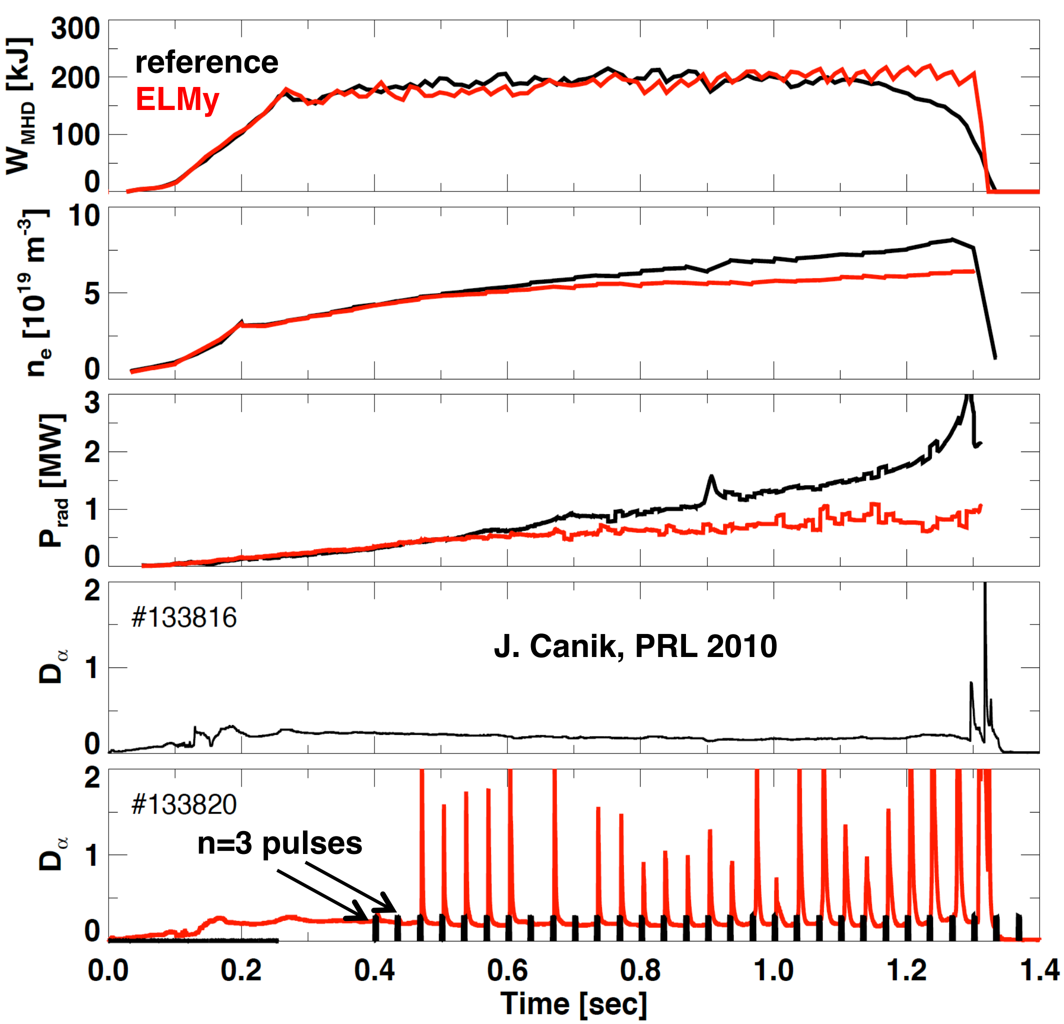
Transport barrier widens continuously with increasing pre-discharge lithium, i.e. pedestal-top D, χ_e reduced



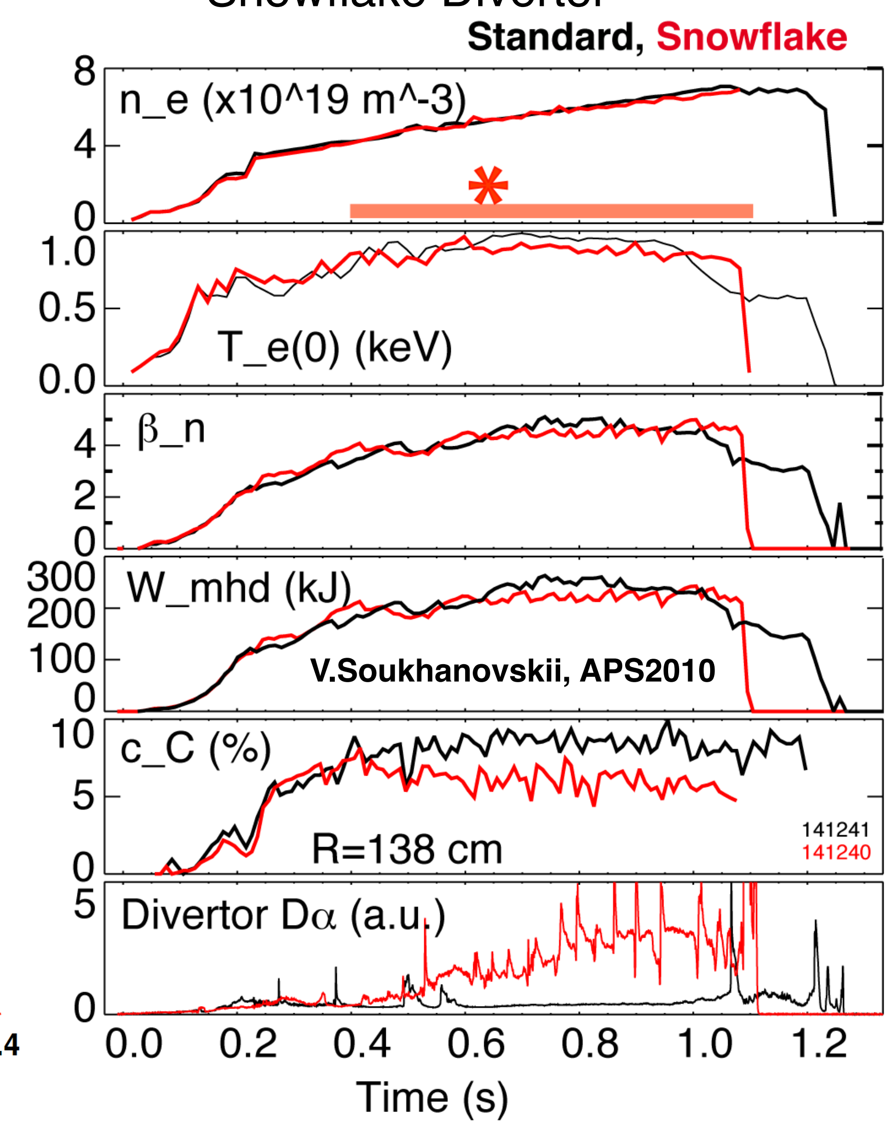
J. Canik, PoP 2011

3D external fields used to trigger ELMs, while "Snowflake Divertor" used to reduce edge impurity source

Type I ELMs triggered for impurity control (post-lithium, n=3)



Snowflake Divertor



T_e, T_i increased and edge n_e decreased with lithium; T_i and Z_{eff} offset so pressure profile followed P_e