Effect of Lithium Evaporation on the Edge Plasma in NSTX, and plans for NSTX-U

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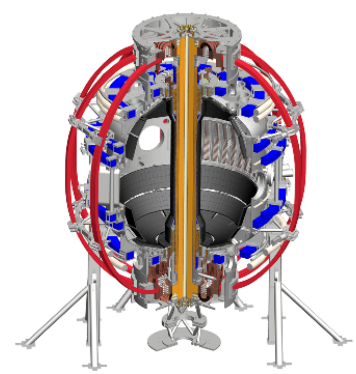


Plasma characteristics and stability improved with increasing lithium evaporation in strongly shaped NSTX discharges

- Lithium evaporated before each discharge
  - Deposition amount scanned, as also in weakly shaped discharges

    (no liquid lithium divertor results in this talk)

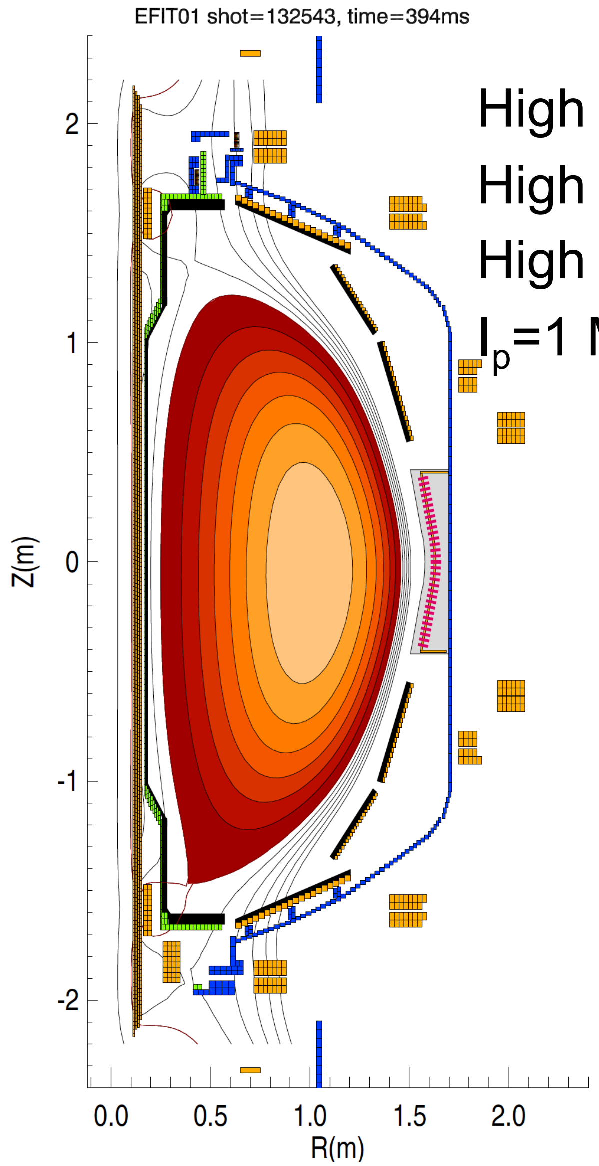
- Global characteristics changed
  - Recycling: D_α declined in all measured views
  - Energy confinement (τ_E, H-factor) improved
  - When discharges were ELM-free, radiated power increased with time *(several techniques developed to deal with this problem)*

- Edge n_e, T_e, pressure profiles changed
  - Reduction in edge n_e gradient changed edge P', improving MHD stability and eliminated ELMs in weakly shaped discharges

Outline

- Effect of lithium on individual discharges
- Trends vs. pre-discharge lithium dose
- Effect on edge profiles
- SOLPS edge transport analysis

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

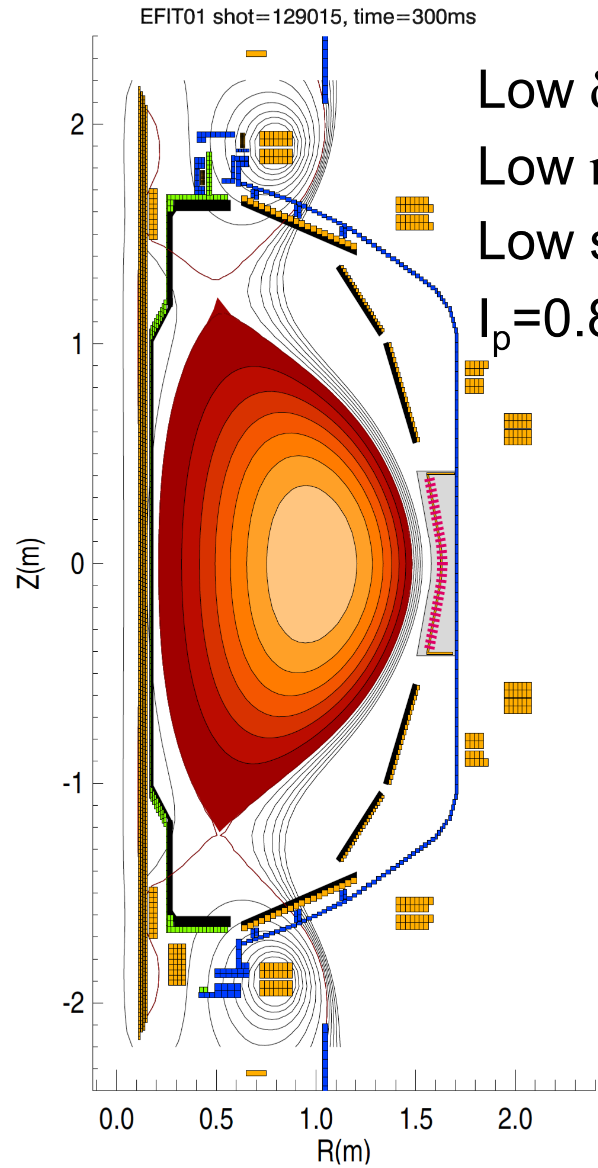


High δ (0.6)

High κ (2.2)

High squareness

I_p=1 MA, q_{95}=8.2



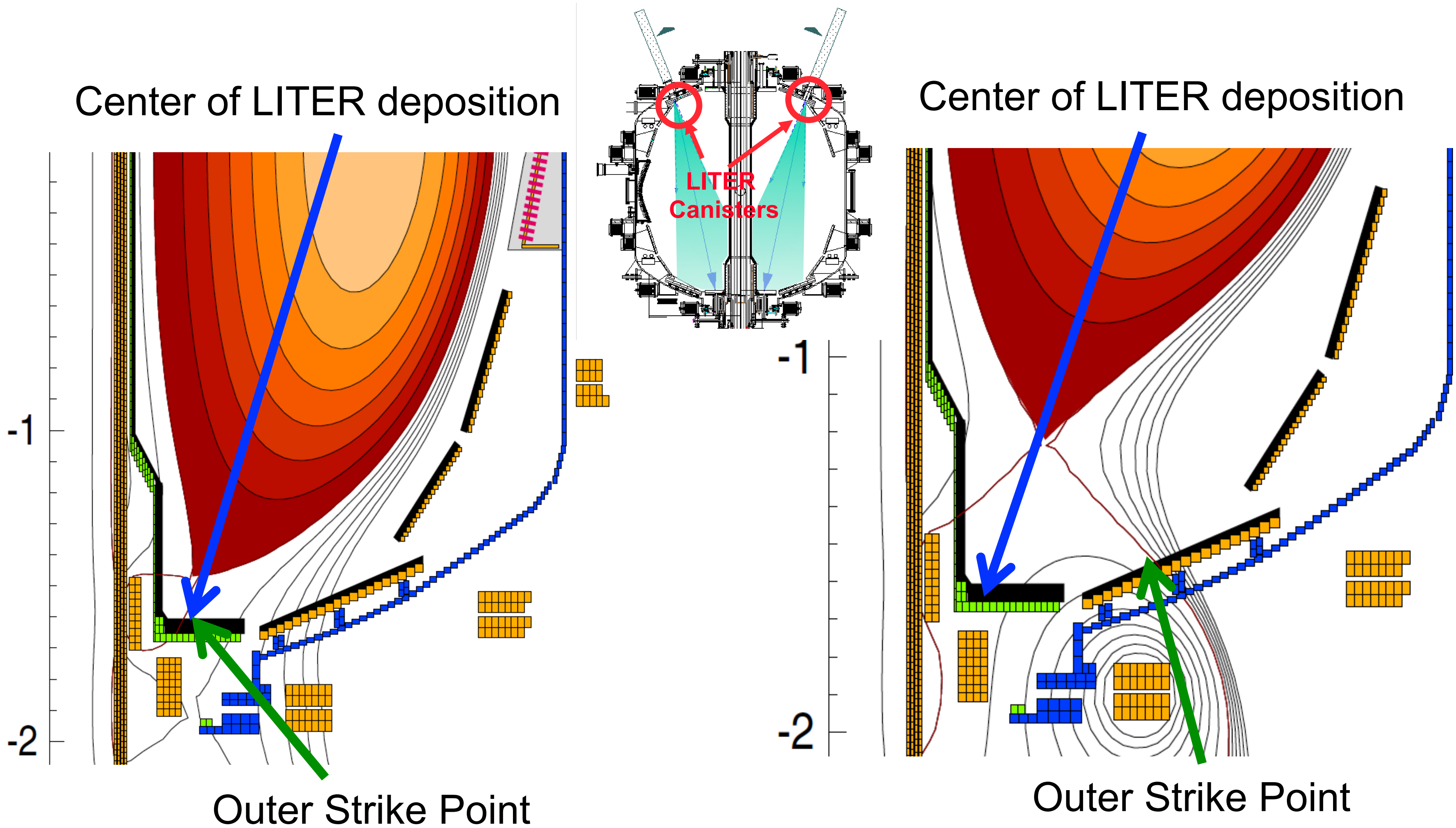
Low δ (0.46)

Low κ (1.8)

Low squareness

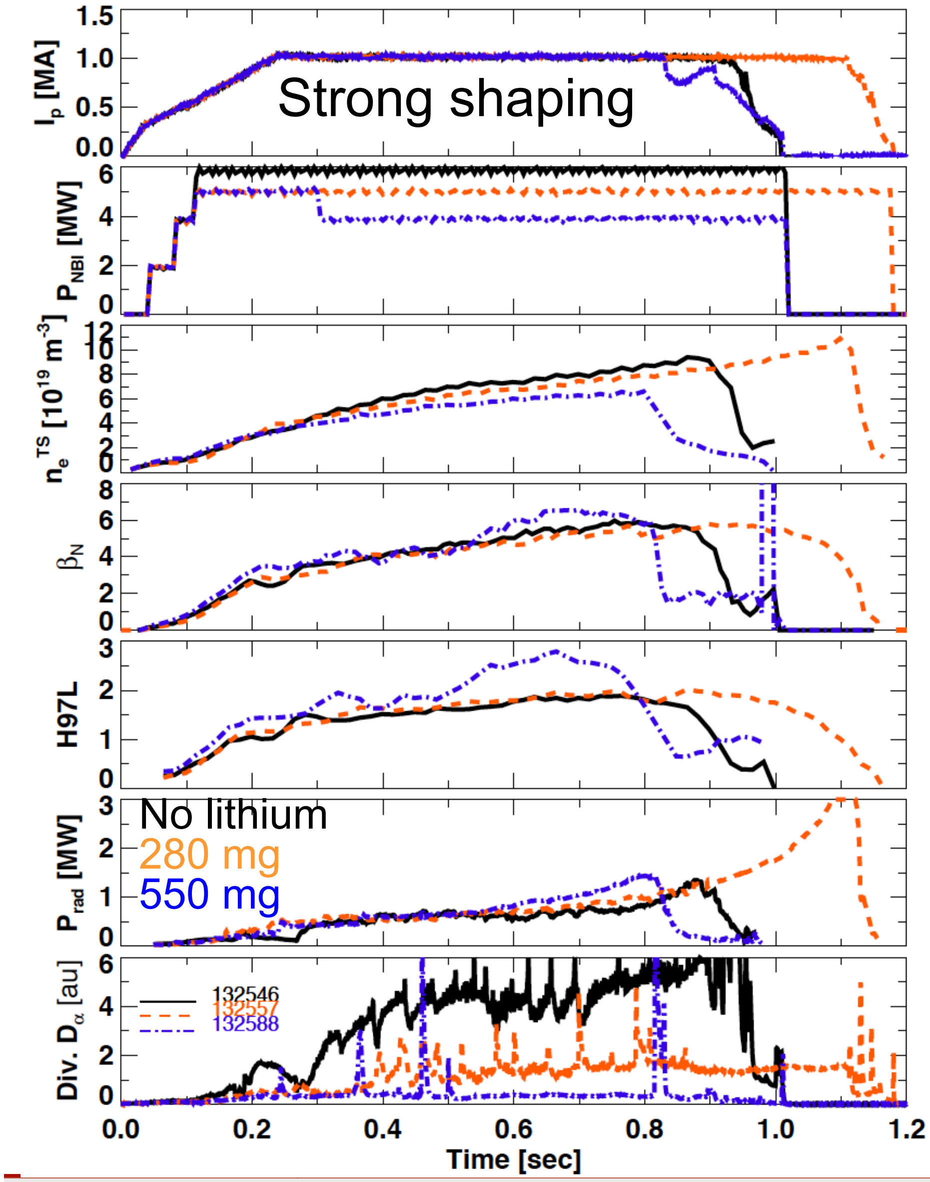
I_p=0.8 MA, q_{95}=7.6

Center of LITER deposition very near (*far from*) outer strike point in high (*low*) triangularity discharges



R. Maingi et al., *J. Nucl. Mater*. **463** (2015) 1186

Performance of strongly shaped discharges improved more with increasing lithium (similar to weakly shaped discharges)

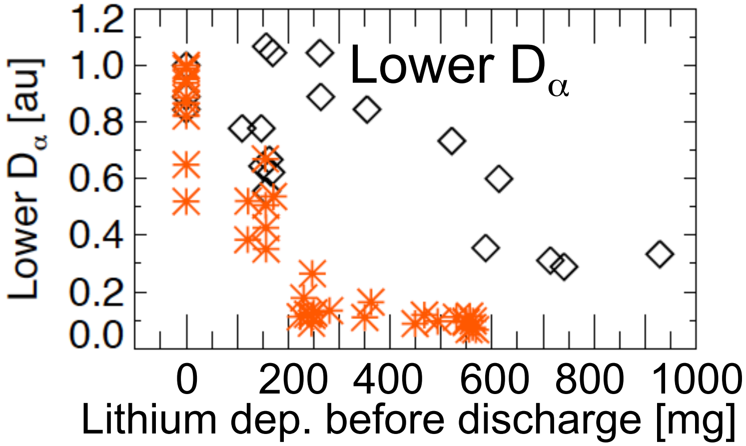


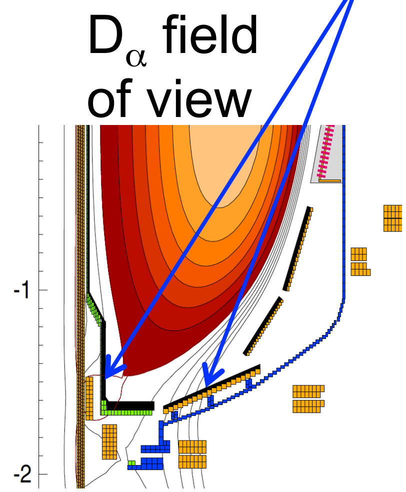
- I_p duration not quite optimized with higher Li
- Reduced P_{NBI}
- Reduced dN/dt
- Comparable stored energy
- H-factor increased by 50%
- Increasing P_{rad} wo/ELMs

F. Scotti et al., *Nucl. Fusion* **53** (2013) 083001

- Reduced recycling, long ELM-free phases

Lower divertor D_α decreased rapidly with increasing Li deposition in highly shaped discharges



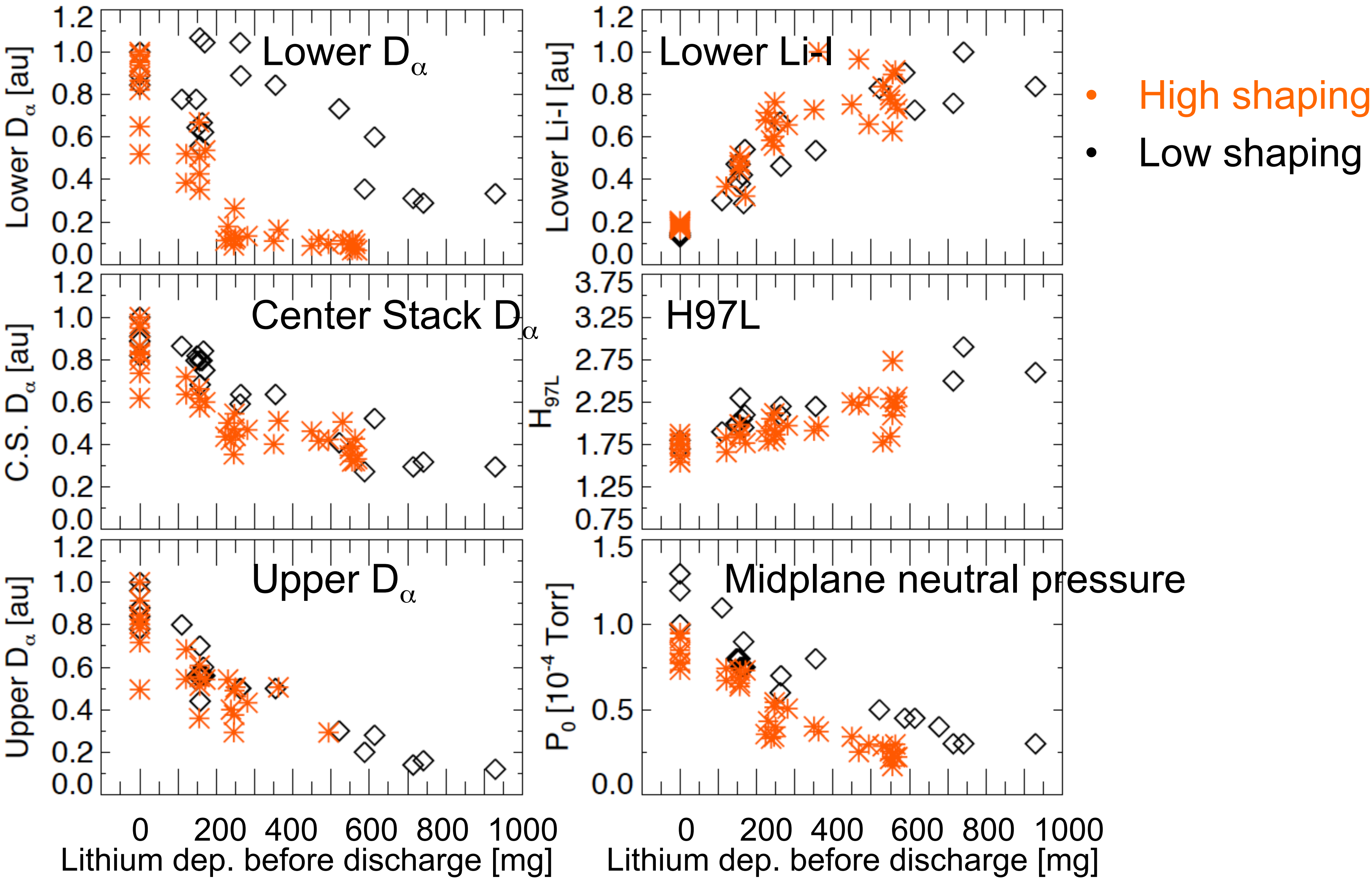


- High shaping
- Low shaping

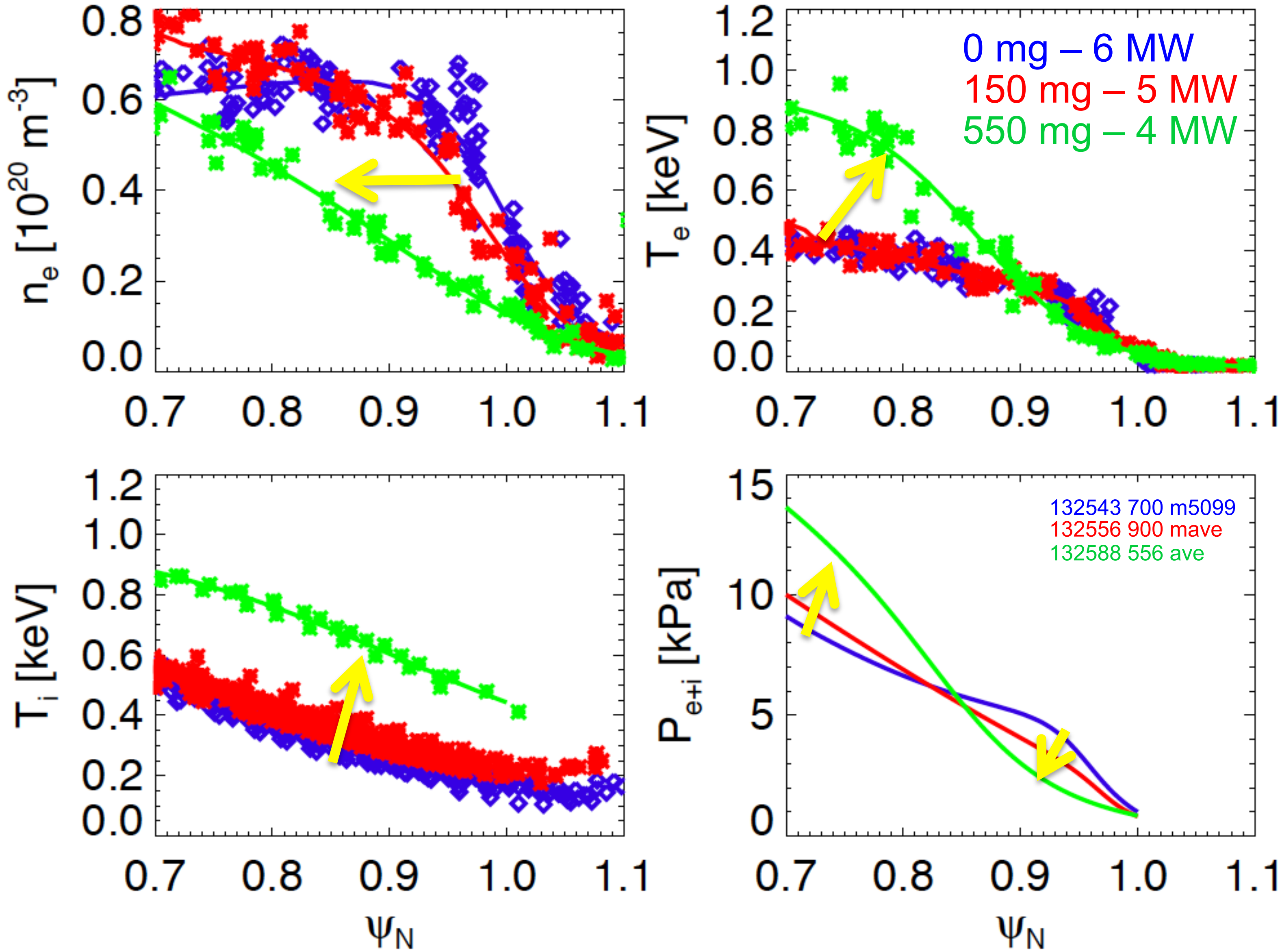
- 5x drop in D_α drop because of transition from high recycling to low recycling
  - Partial detachment in highly shaped no-Li discharges?

- Possible geometric effect: Li deposition closer to outer strike point and/or high flux expansion facilitates transition from high to low recycling at lower Li deposition in highly shaped discharges

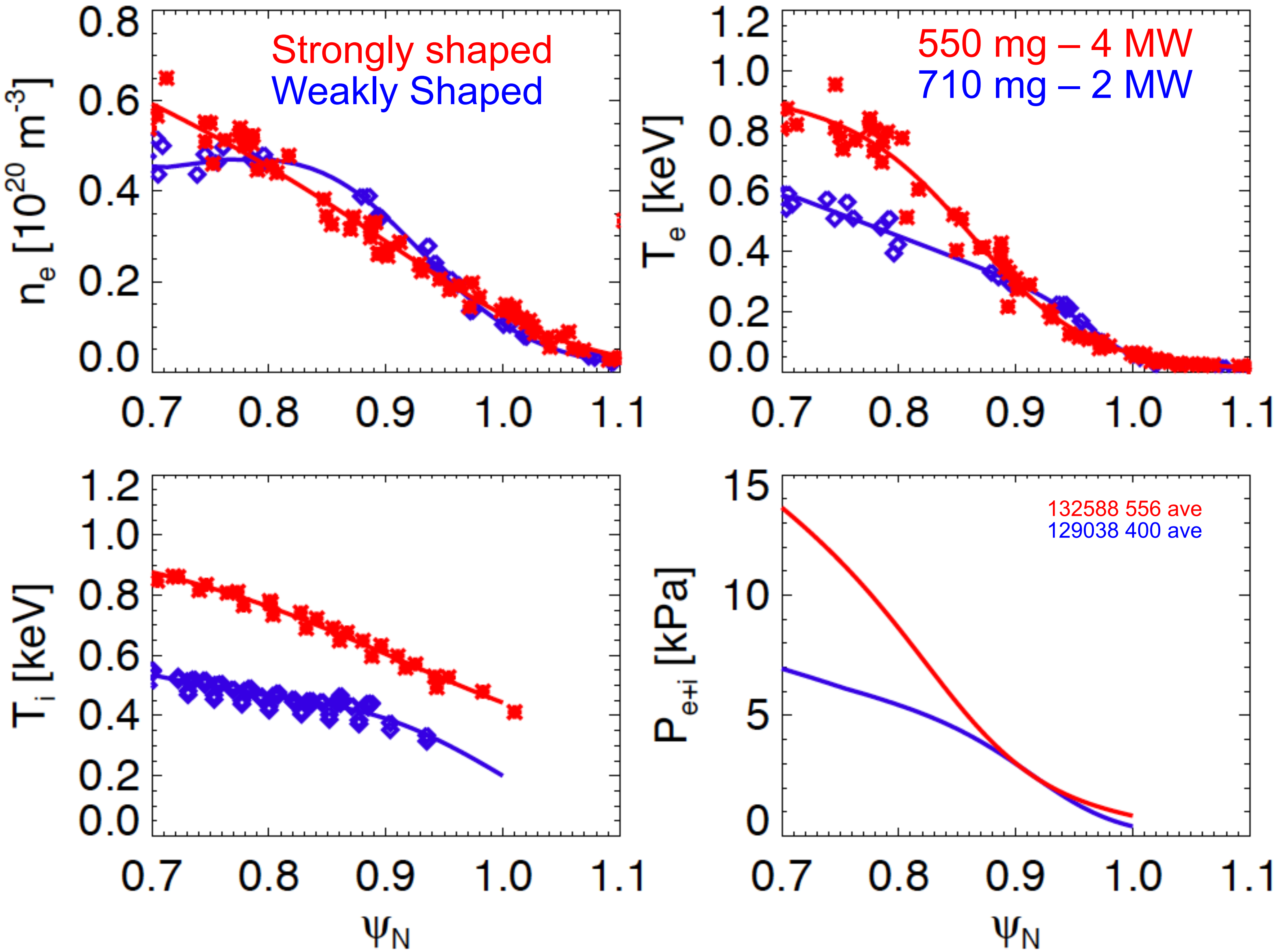
D_α and neutral pressure decreased, and H97L increased with increasing pre-discharge lithium evaporation in all data



Edge profiles change markedly with increasing lithium in strongly shaped discharges *(as in weakly shaped ones)*



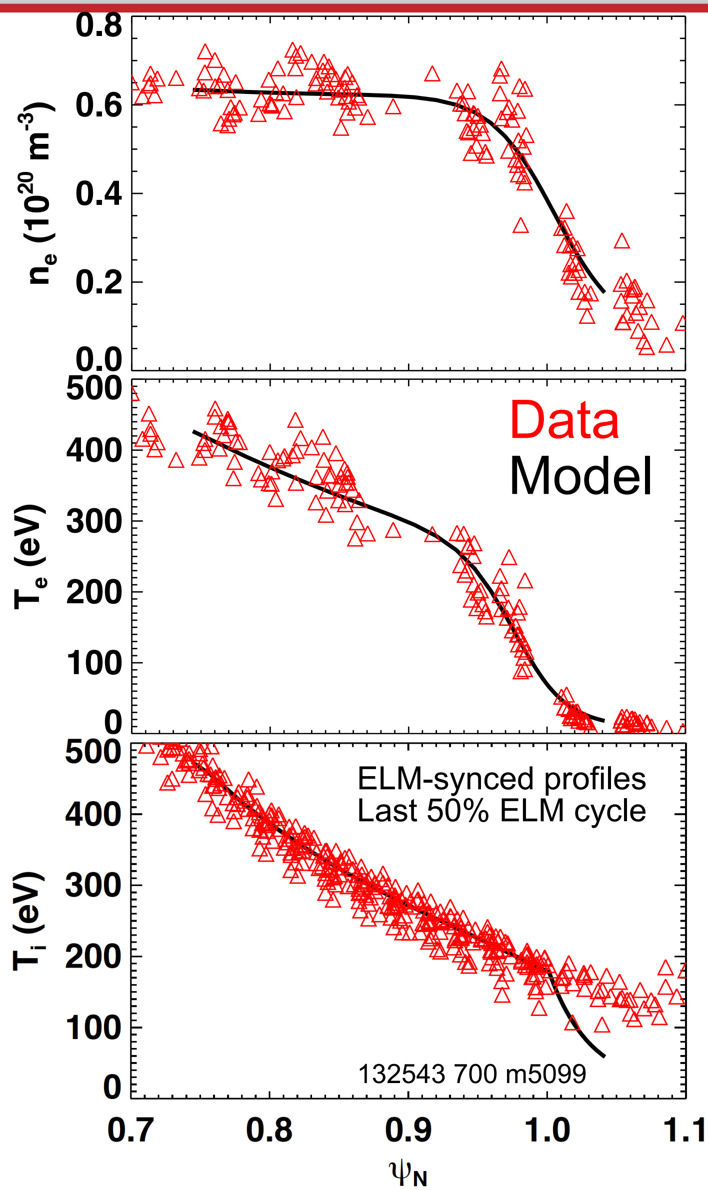
Higher NBI power in strongly shaped discharges leads to high edge temperature and pressure

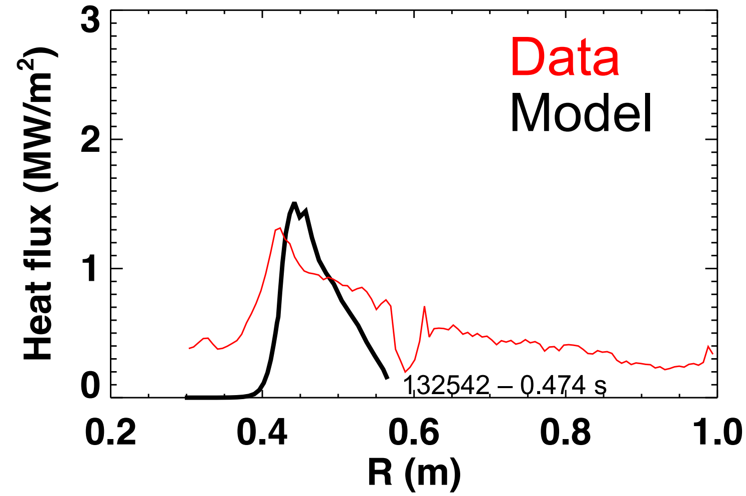


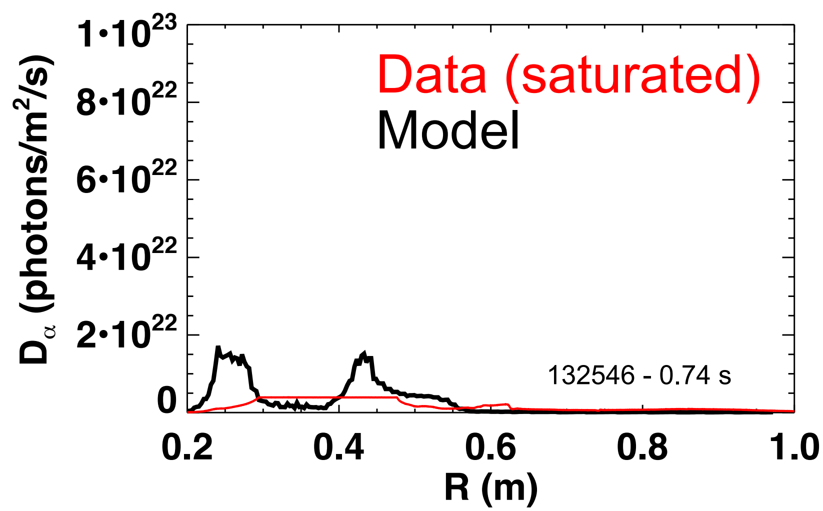
Goal of SOLPS interpretive analysis is to assess recycling coefficient and radial transport changes with lithium

- Generate grid based on discharge equilibrium
- Prescribe power and particle fluxes through inner boundary from data
- Vary free parameters to match measured midplane and divertor profiles
  - Separatrix location adjusted to match peak q_{div}^{peak}
  - ✓ Plate recycling coefficient and radiation varied to match peak D_{α}
  - ✓ Extra power-balance iteration allows complex $D(\psi)$, $\chi(\psi)$
  - No separation between D and v_{pinch}, so diffusivities are 'effective' values, i.e. to get flux right
- Result: recycling coefficient drops f/0.99 to ~0.9
- Result: transport increases in last 3% of ψ_N, but decreases inside of that region

Reference no-lithium discharge has low heat flux & high D_α: modeling indicates partially detached state

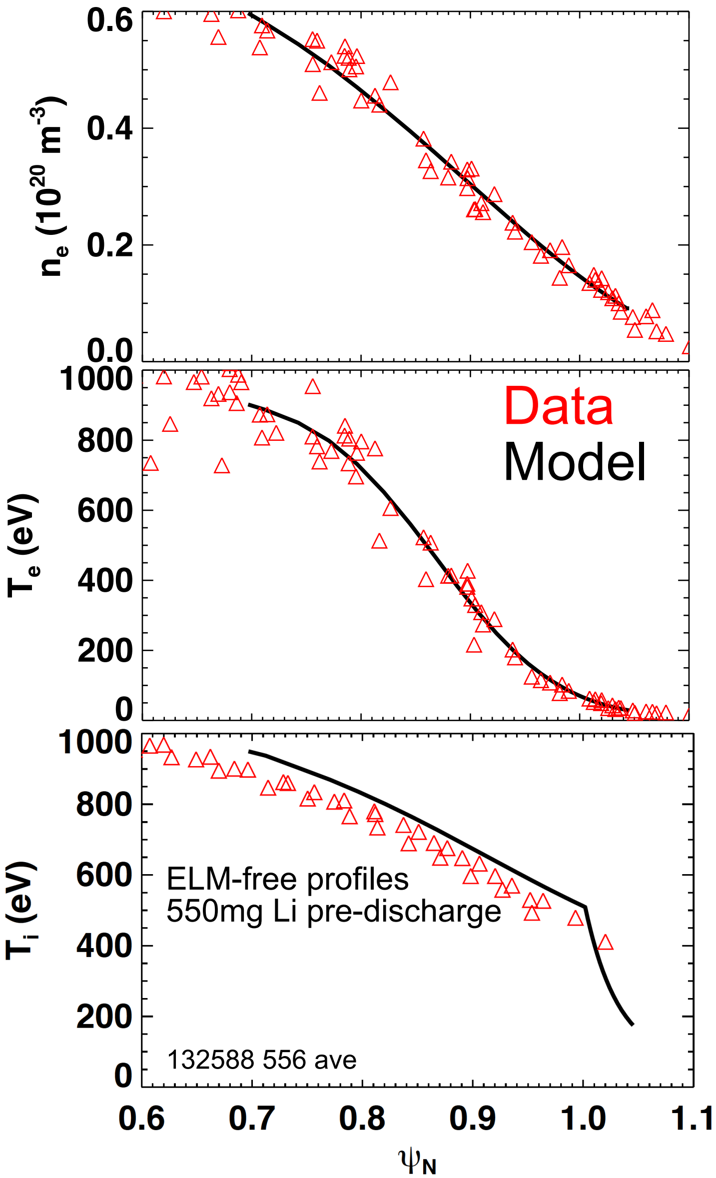


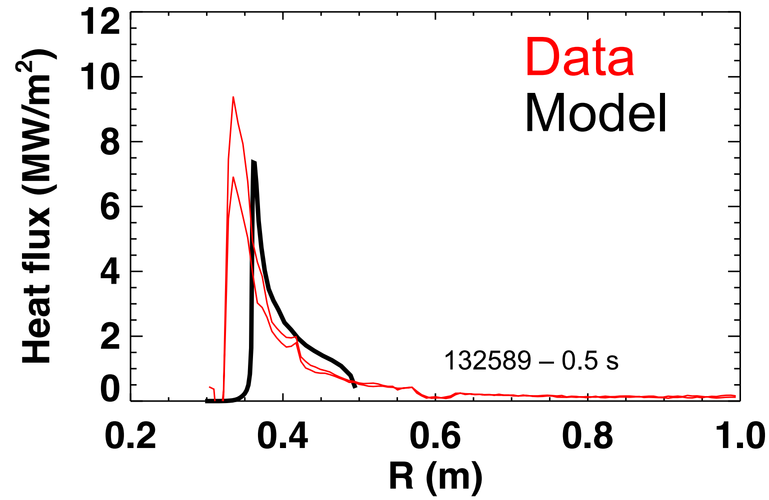


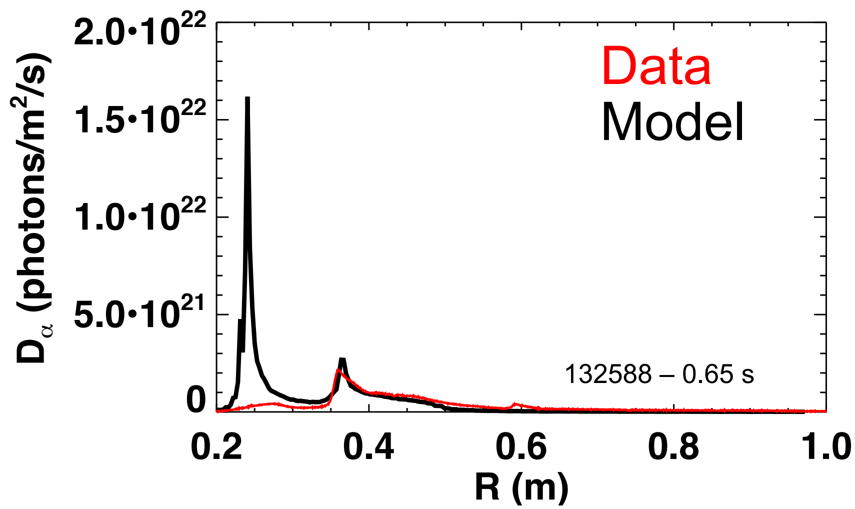


* D_α saturated from R=0.3-0.47m

Shallow edge n_e gradient, deeper temperature gradients, and higher heat flux/lower D_α reproduced in modeling

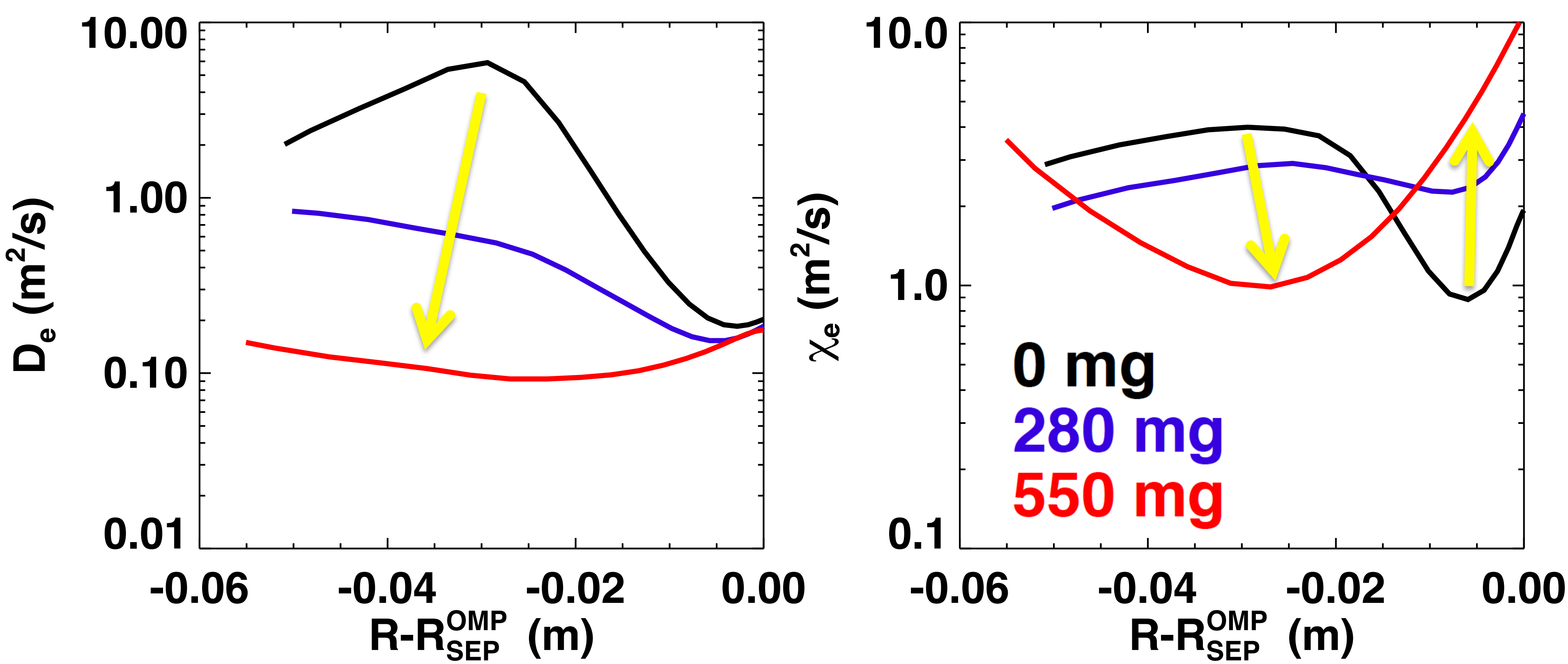






* Uncertainty in peak heat flux due to lithium use, no dual-band adapter

Particle transport reduced with increasing lithium
Energy transport reduced a few cm insides of separatrix



- Increasing lithium in direction of yellow arrow

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

- Recycling and neutral pressure decreased with increasing Li
- Energy confinement increased and edge stability improved with increasing Li
  - Divertor peak heat flux also increased substantially
- Recycling coefficient dropped to ~ 0.9 from 0.99 (SOLPS)
  - Li deposition close to strike point facilitates high -> low recycling?
- Transport increased in last 3% of ψ_N, but decreased inside of that region (SOLPS)
- Change in edge profiles likely the key to ELM elimination, as in weakly shaped discharges
  - ELITE edge stability calculations commencing
  - Micro-stability assessment in progress

Lithium delivery tools being developed for NSTX-U

- Downward facing evaporators ~ Jan. 2016 (first lithium in NSTX-U: controlled scan as reported here)
- Upward facing evaporators ~ Fall 2016
- Impurity granule injector (ELM pacing, including, carbon, lithium, etc – see Lunsford poster) ~ Dec. 2015
- Lithium dropper ~ needs re-installation of guide tube (Fall 2016+)
- Pre-loaded lithium targets in divertor tiles ~ Fall 2017

- **Looking forward to conducting these types of experiments in NSTX-U!**

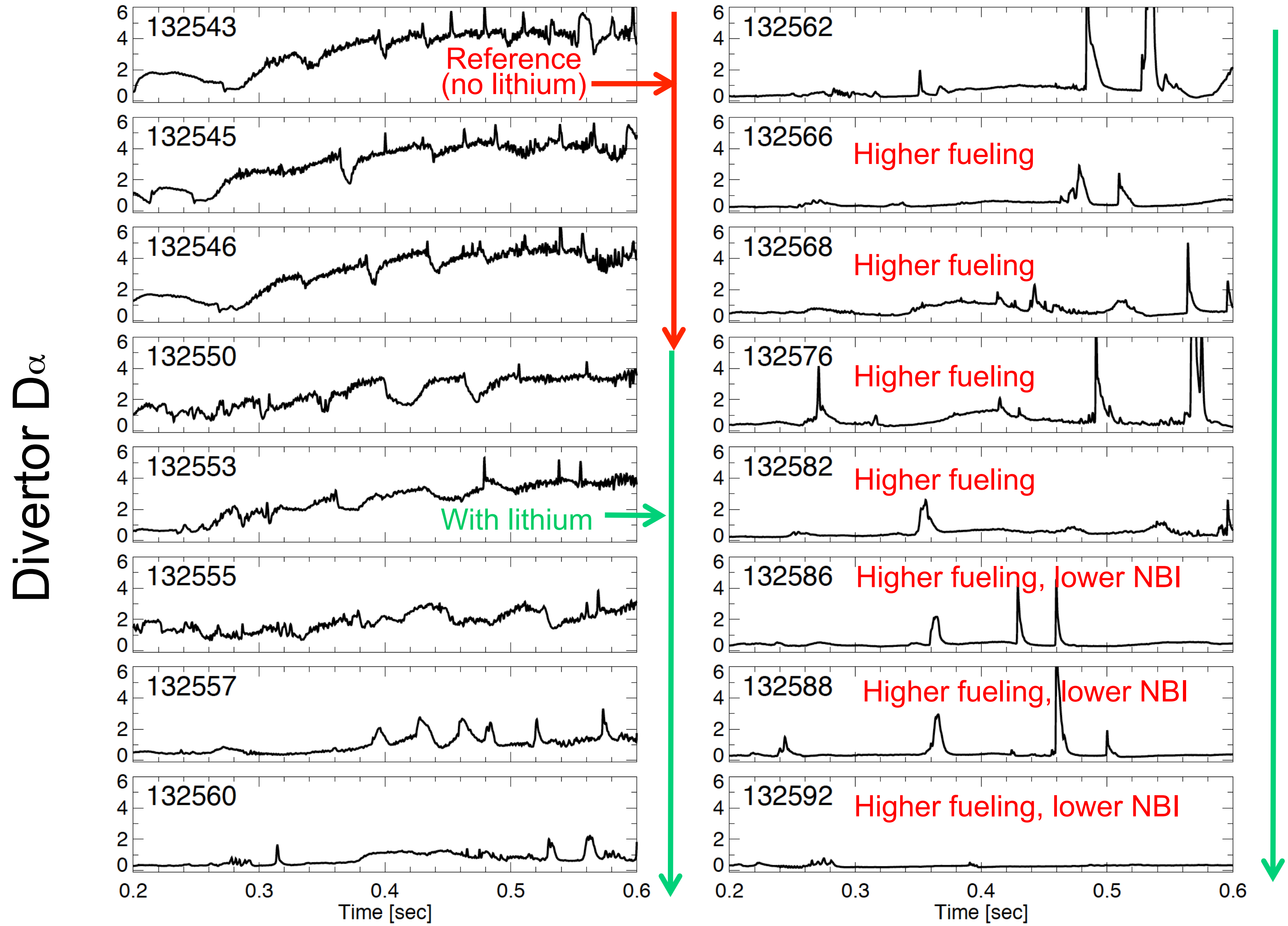
Backup

Comparison of lithium results from NSTX, DIII-D, and EAST

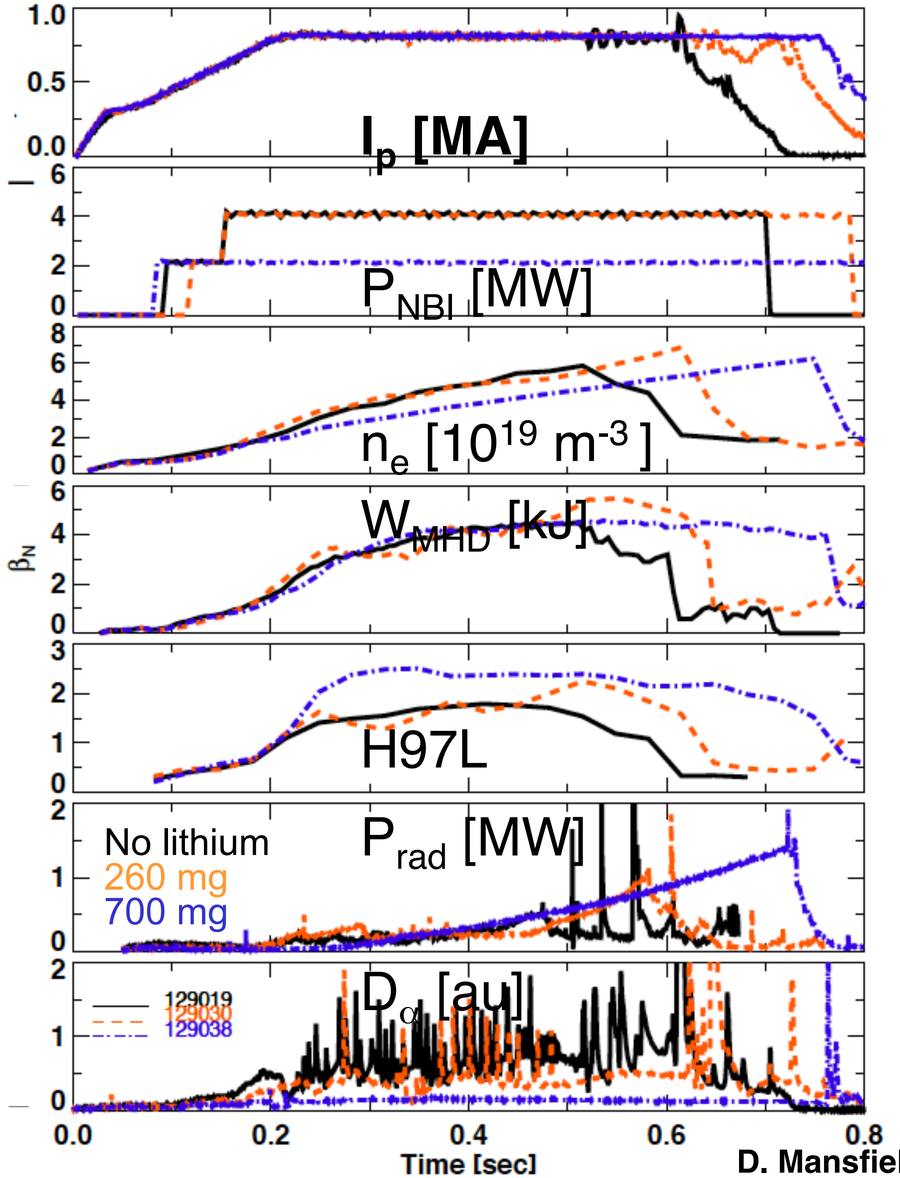
	NSTX	DIII-D*	EAST**
Delivery method	Inter-shot evaporation, (Dropper)	Dropper	Dropper, (Morning evap., FLiLi Limiter)
Pedestal Width	**Increased**	**Increased**	**?**
Pedestal Height	**Increased**	**Increased**	**?**
H-factor	**Increased**	**Increased**	**Unchanged**
Edge fluctuations	**Decreased**	**Increased**	**Increased**
Radiated power	**Ramp during ELM-free phase**	**Steady in ELM-free phase**	**Steady in ELM-free phase**
Effect on ELMs	**Eliminated**	**Delayed**	**Eliminated**
Recycling	**Reduced**	**Unchanged**	**Reduced**

* DIII-D: T.H. Osborne, *Nucl. Fusion* **55** (2015) 063018
** EAST: J.S. Hu, *Phys. Rev. Lett.* **114** (2015) 055001

ELMs disappeared gradually with increasing lithium
(*also observed in weakly shaped discharges*)



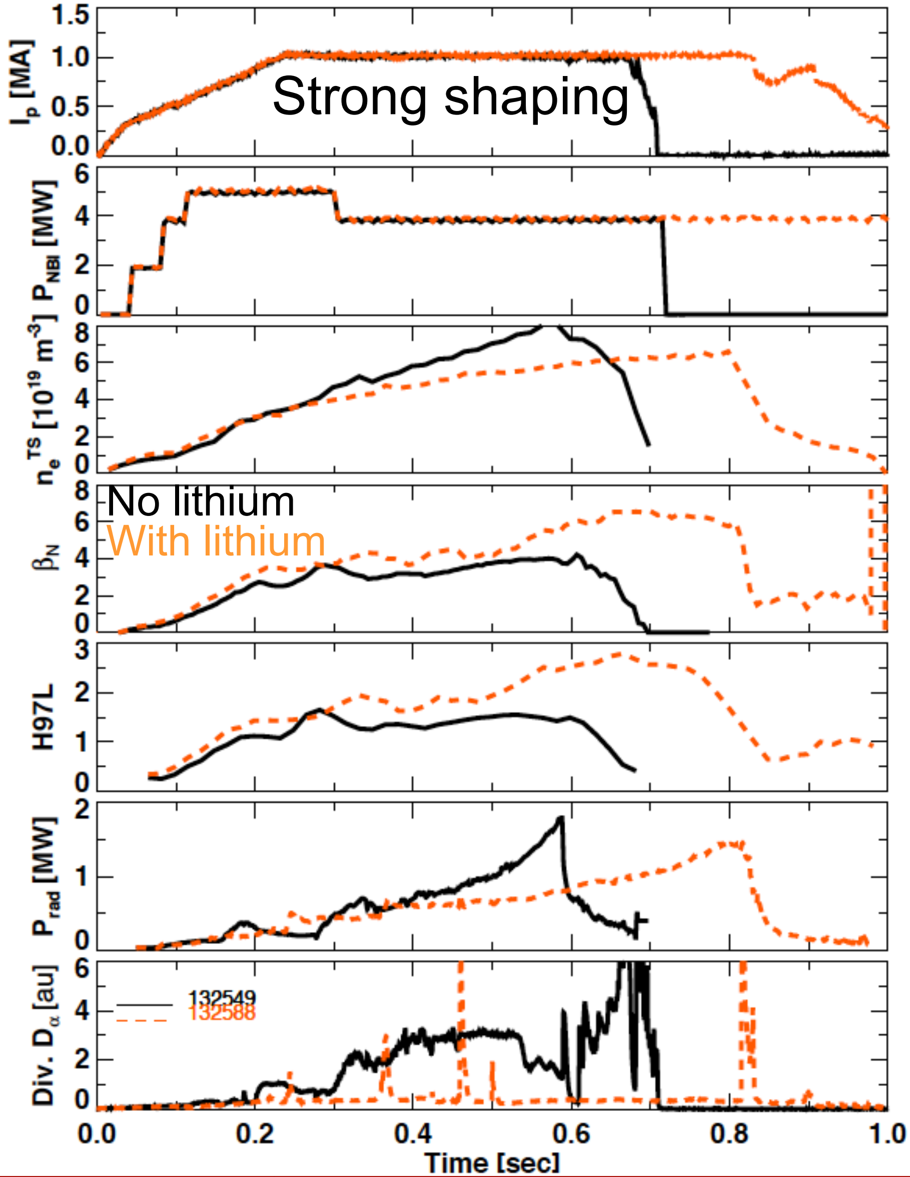
ELM-free H-mode induced by lithium wall conditioning in weakly shaped discharges



- Pre-Li, with-Li (260 mg), with-Li (700 mg)
- Lower NBI to avoid β limit
- Lower n_e
- Similar stored energy
- H-factor increased by 40%
- Higher P_{rad} /P_{heat}
- Reduced recycling, ELM-free with higher Li

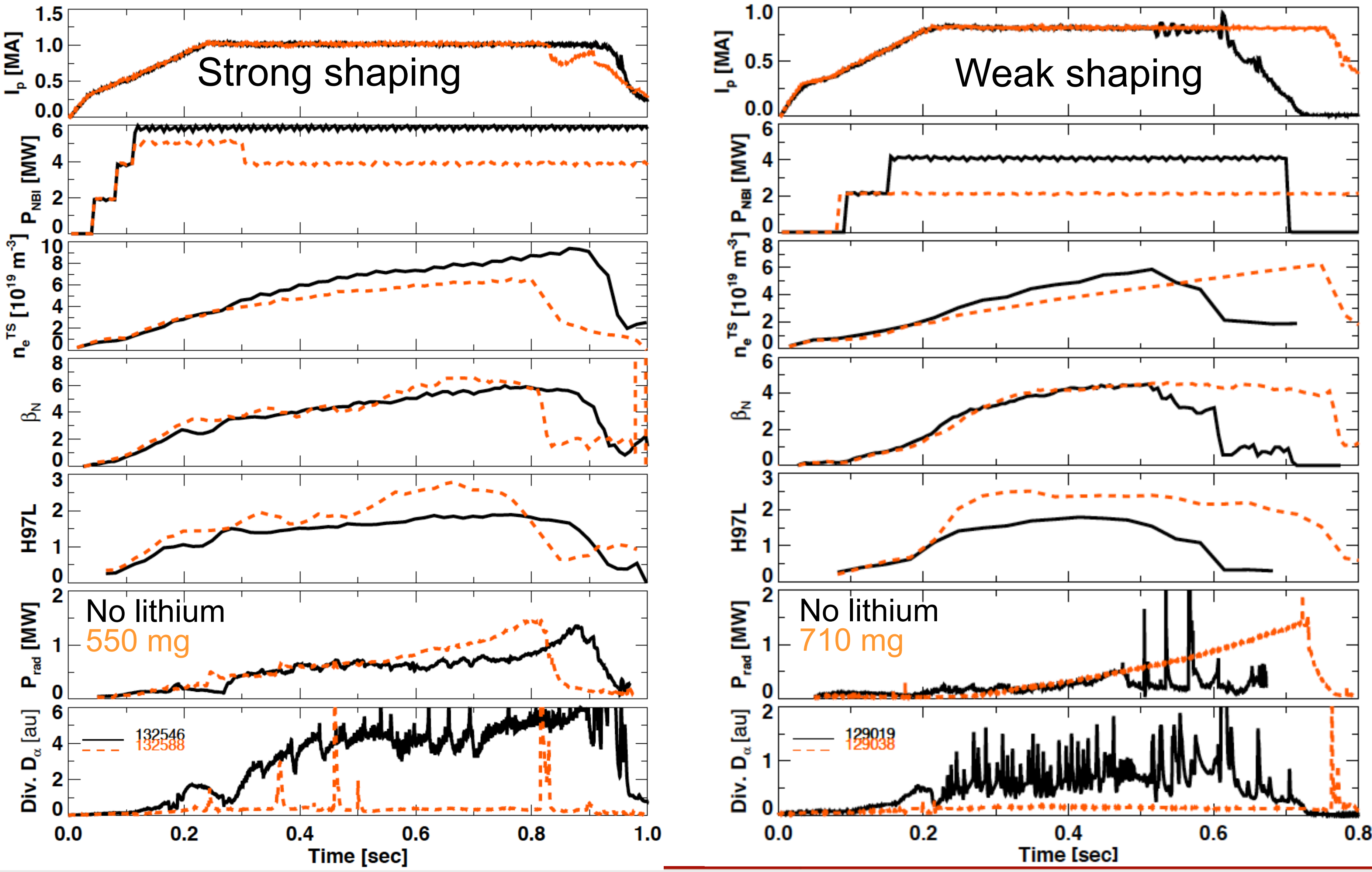
D. Mansfield, JNM 2009; R. Maingi, PRL 2009

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

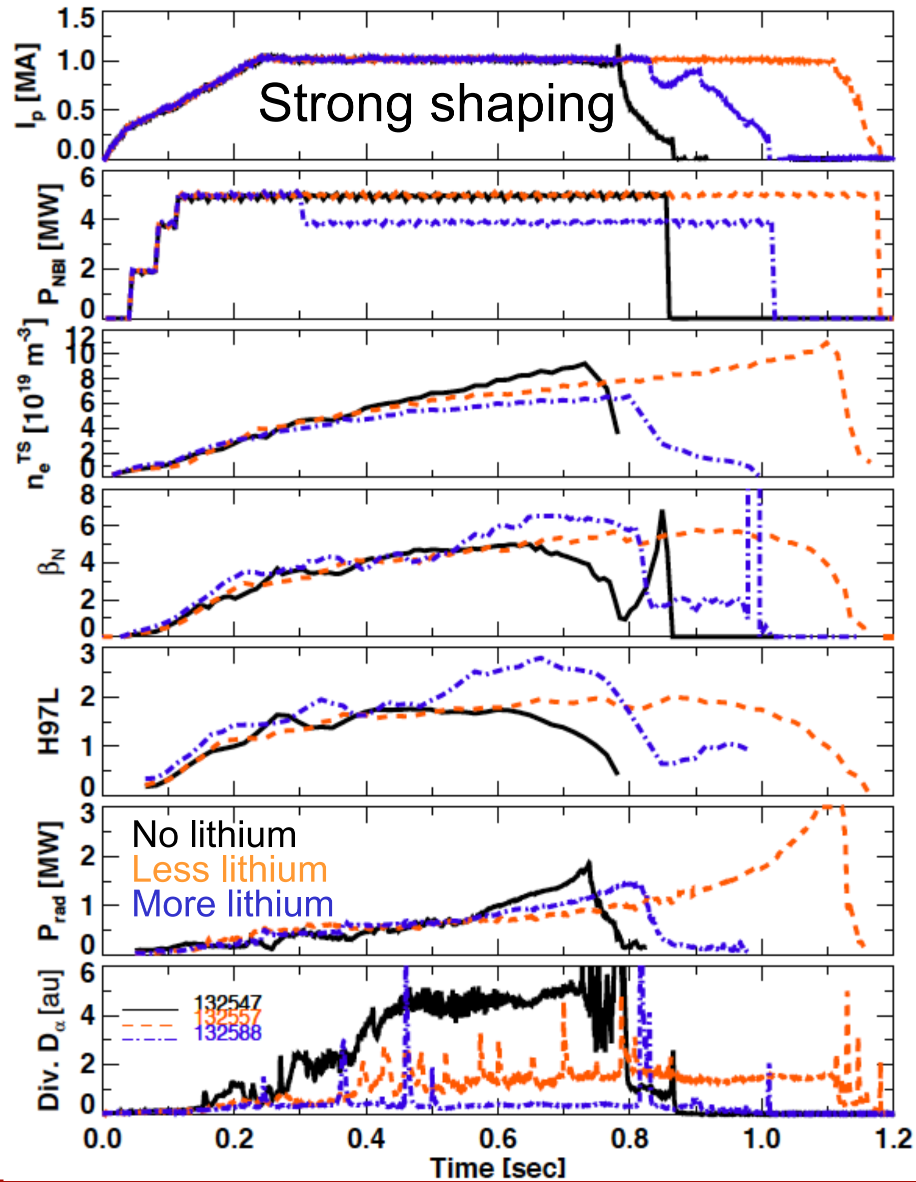


- Duration extended
- Same P_{NBI}
- Reduced dN/dt
- Higher stored energy
- Higher confinement
- Increasing P_{rad}
- Reduced recycling, long ELM-free phases

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

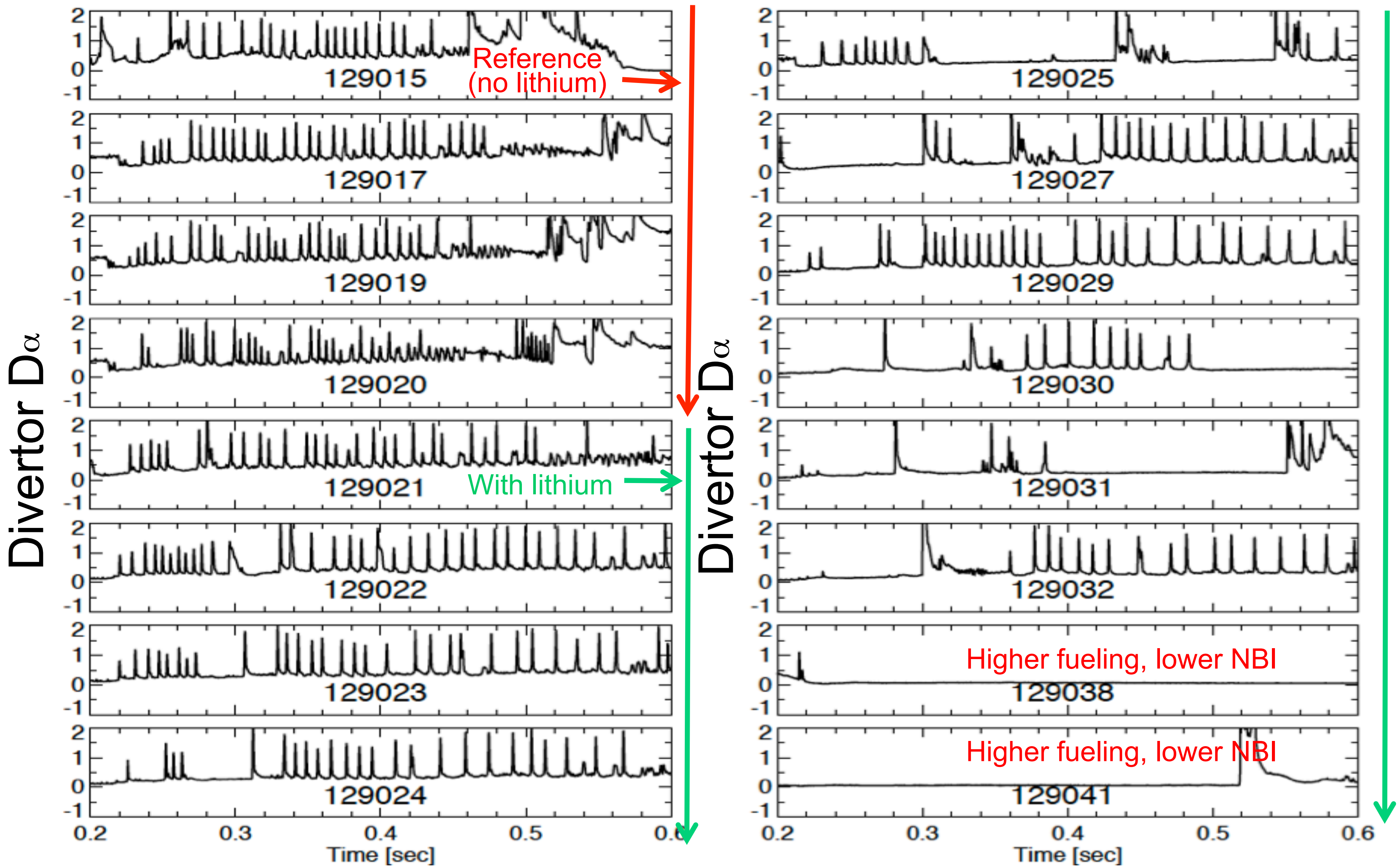


Similar effects on discharges observed with weak and strong shaping



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

ELMs eliminated gradually during original low δ experiment



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 2015

Flow chart of how lithium results in ELM elimination similar for highly and weakly shaped discharges

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)