U.S. DEPARTMENT OF ENERGY | Office of Science

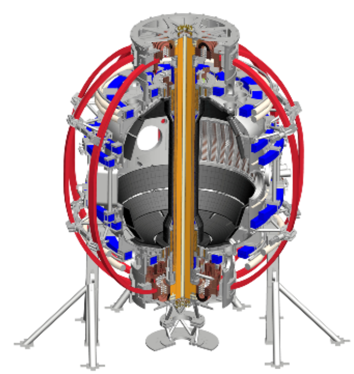
NSTX-U

ELM elimination in high triangularity discharges as a function of Lithium dose in NSTX

R. Maingi (PPPL), J.M. Canik (ORNL), and the NSTX-U Team

57th APS meeting, Division of Plasma Physics
Savannah, GA
16-20 November 2015

PPPL

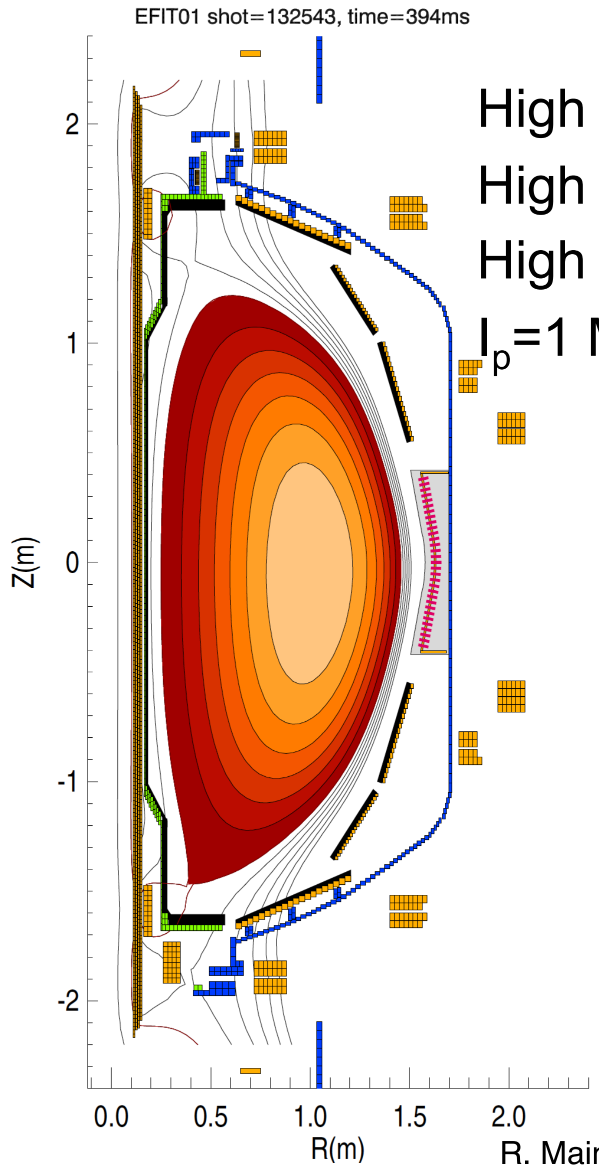


Plasma characteristics and stability improved with increasing lithium evaporation in strongly shaped NSTX discharges

- Lithium evaporated before each discharge onto graphite PFCs
  - Deposition amount scanned *(no liquid lithium divertor results here)*
- 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 were developed to deal with this problem)*
- Edge n_e, T_e, pressure profiles changed
  - Reduction in edge n_e gradient changed edge P', which also improved MHD stability and eliminated ELMs in weakly shaped discharges

1. *Effect on individual discharges*
2. *Trends vs. pre-discharge lithium*
3. *Effect on profiles*
4. *SOLPS edge transport analysis*

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

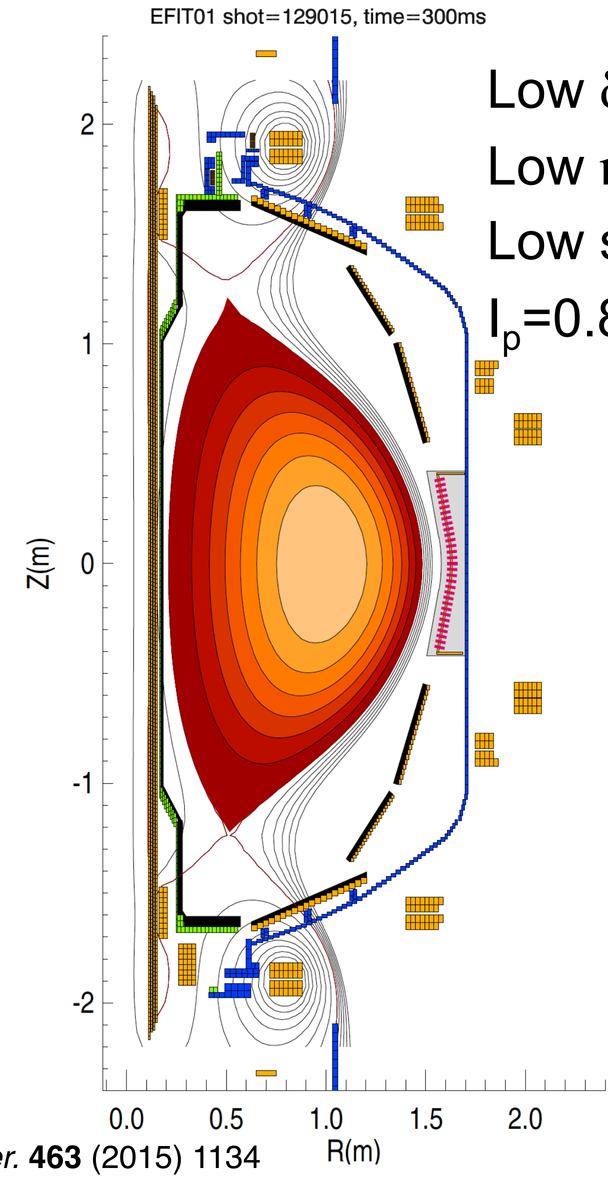


High δ (0.6)

High κ (2.2)

High squareness

I_p=1 MA, q_{95}=8.2



Low δ (0.46)

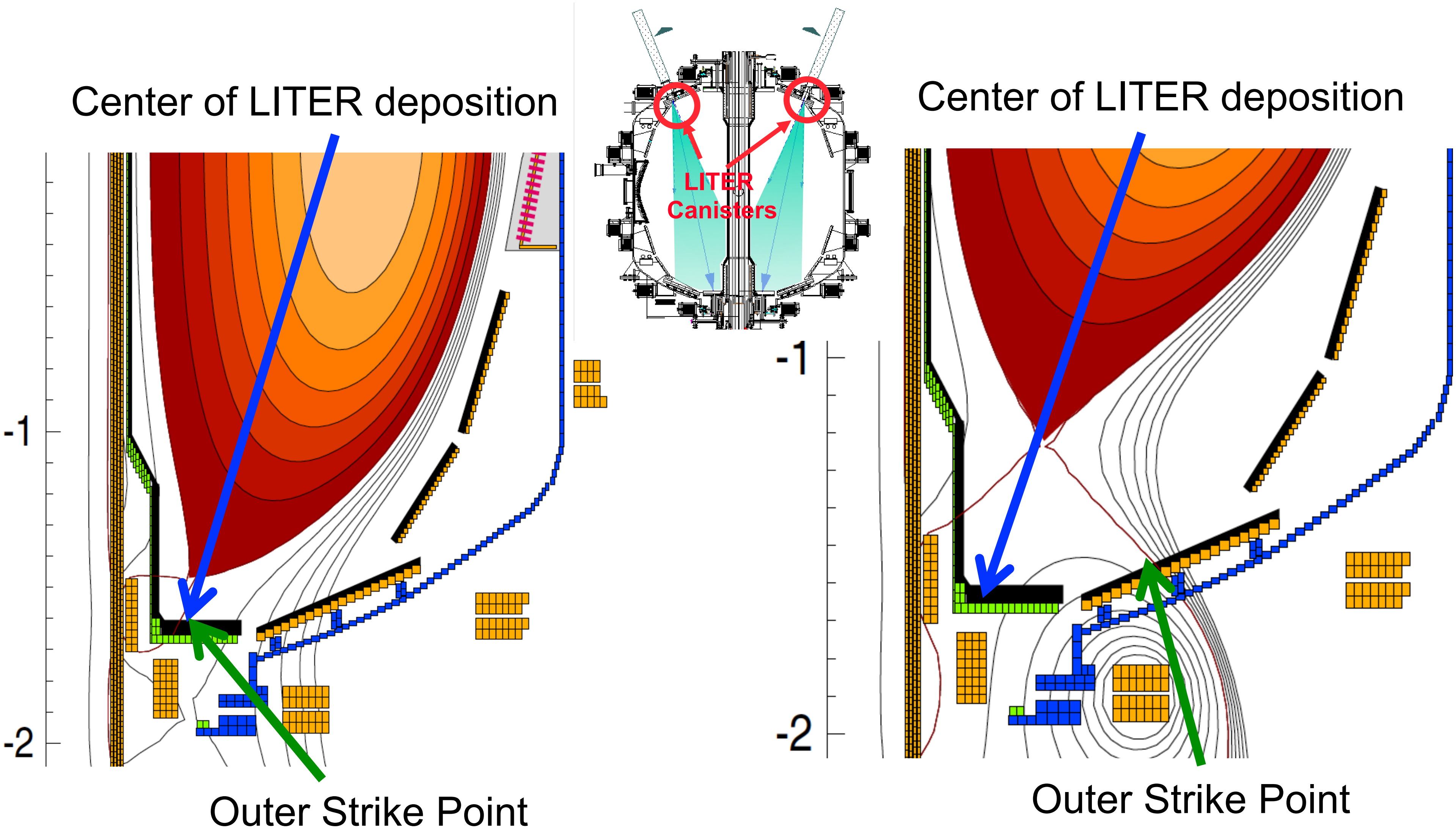
Low κ (1.8)

Low squareness

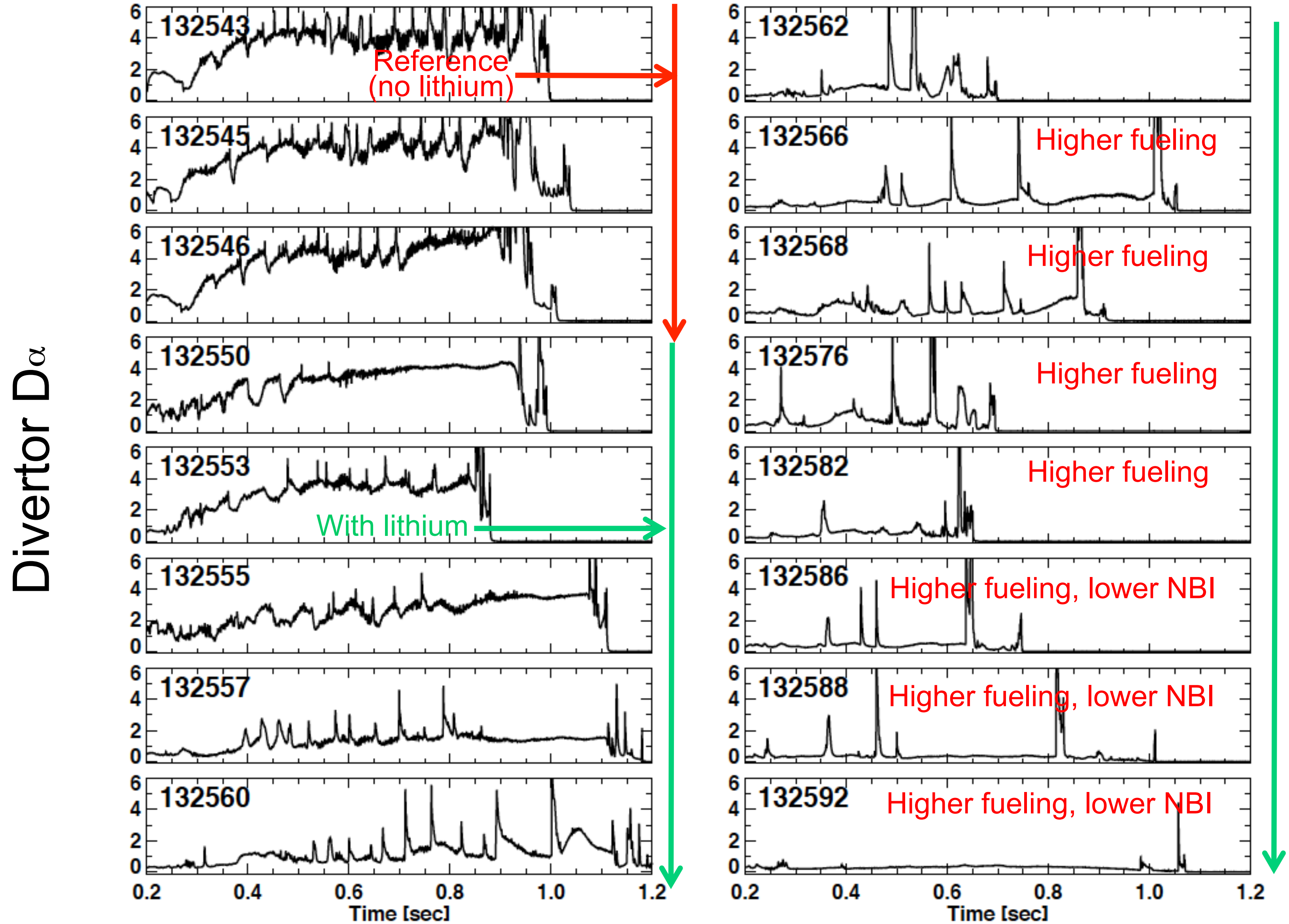
I_p=0.8 MA, q_{95}=7.6

R. Maingi et al., *J. Nucl. Mater.* **463** (2015) 1134

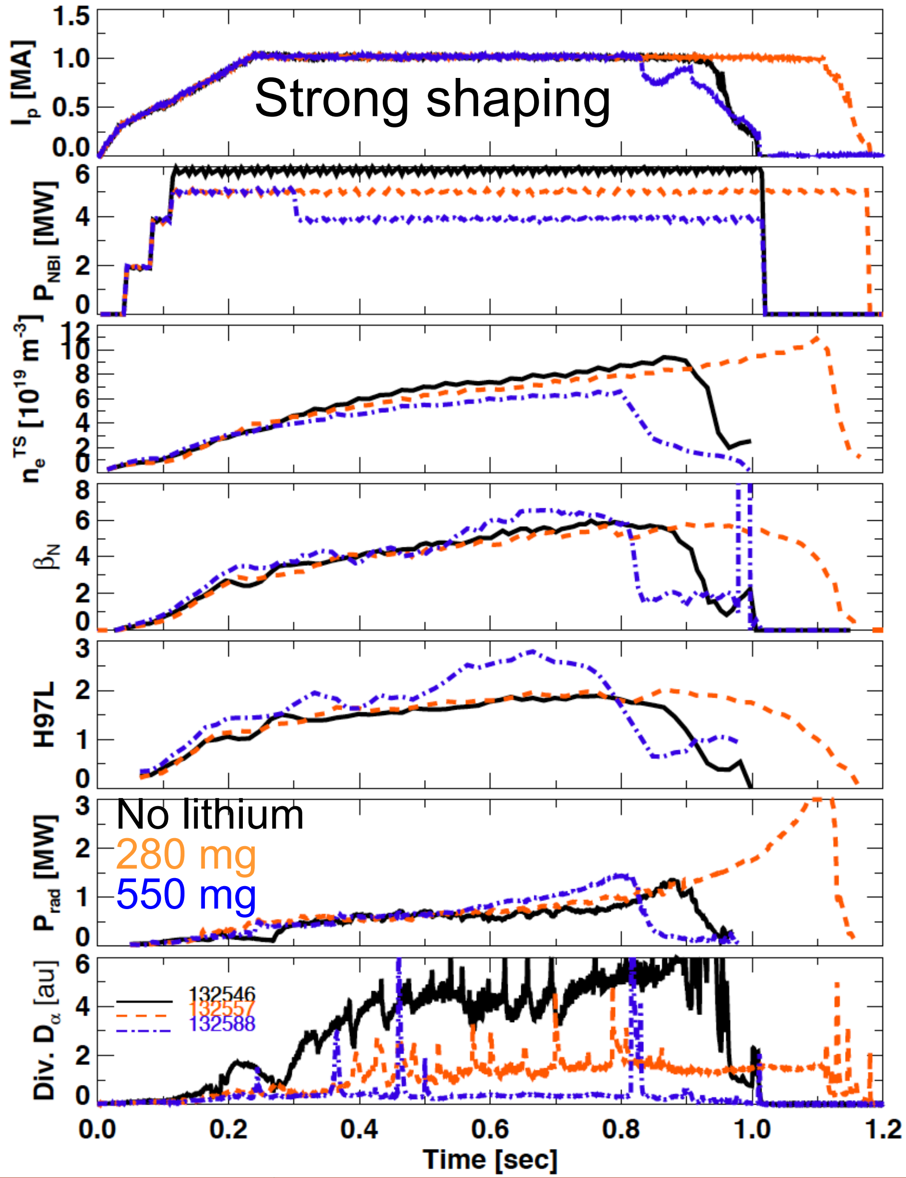
Center of LITER deposition very near (*far from*) outer strike point in high (*low*) triangularity discharges



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



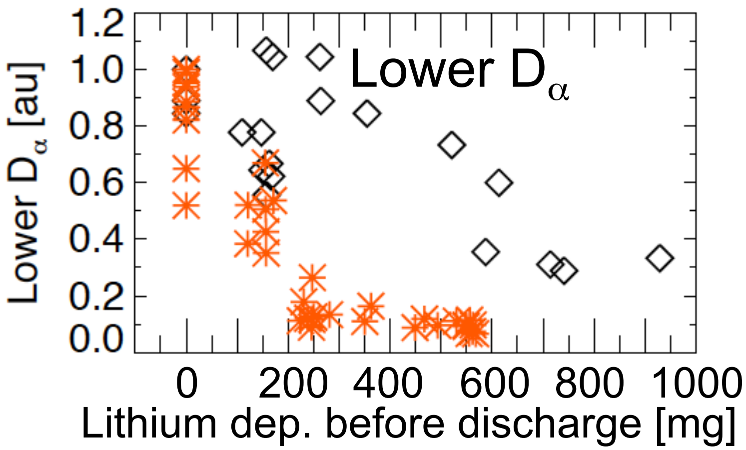
Performance of strongly shaped discharges improved more with increasing lithium (similar to weakly shaped discharges)

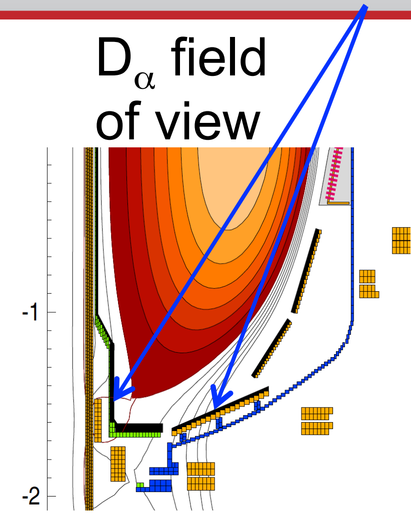


- I_p duration not quite optimized with higher Li
- Reduced P_{NBI}
- Reduced dN/dt
- Comparable stored energy
- H-factor increased by 50%
- Increasing P_{rad} wo/ELMs

  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



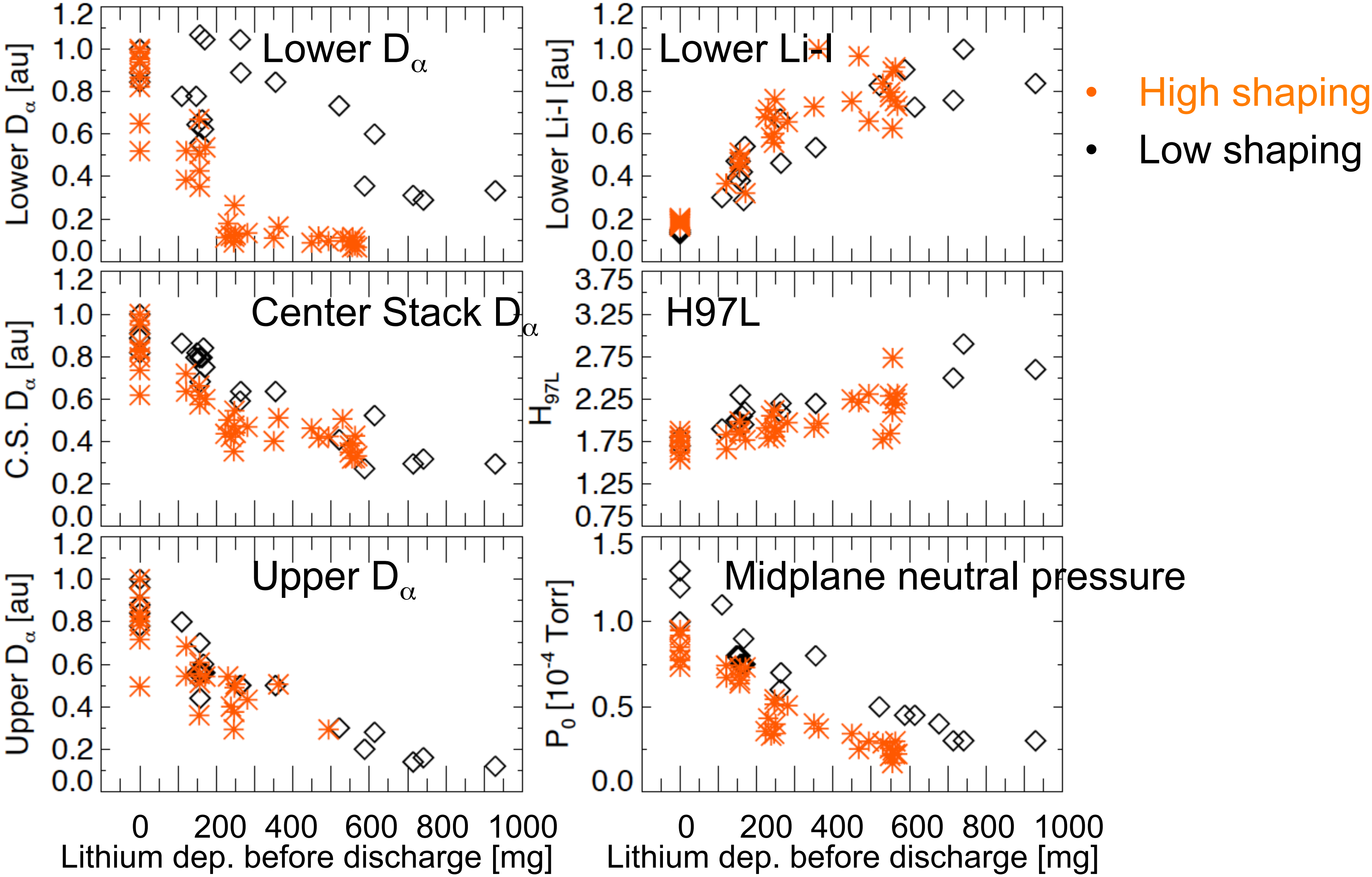


- High shaping
- Low shaping

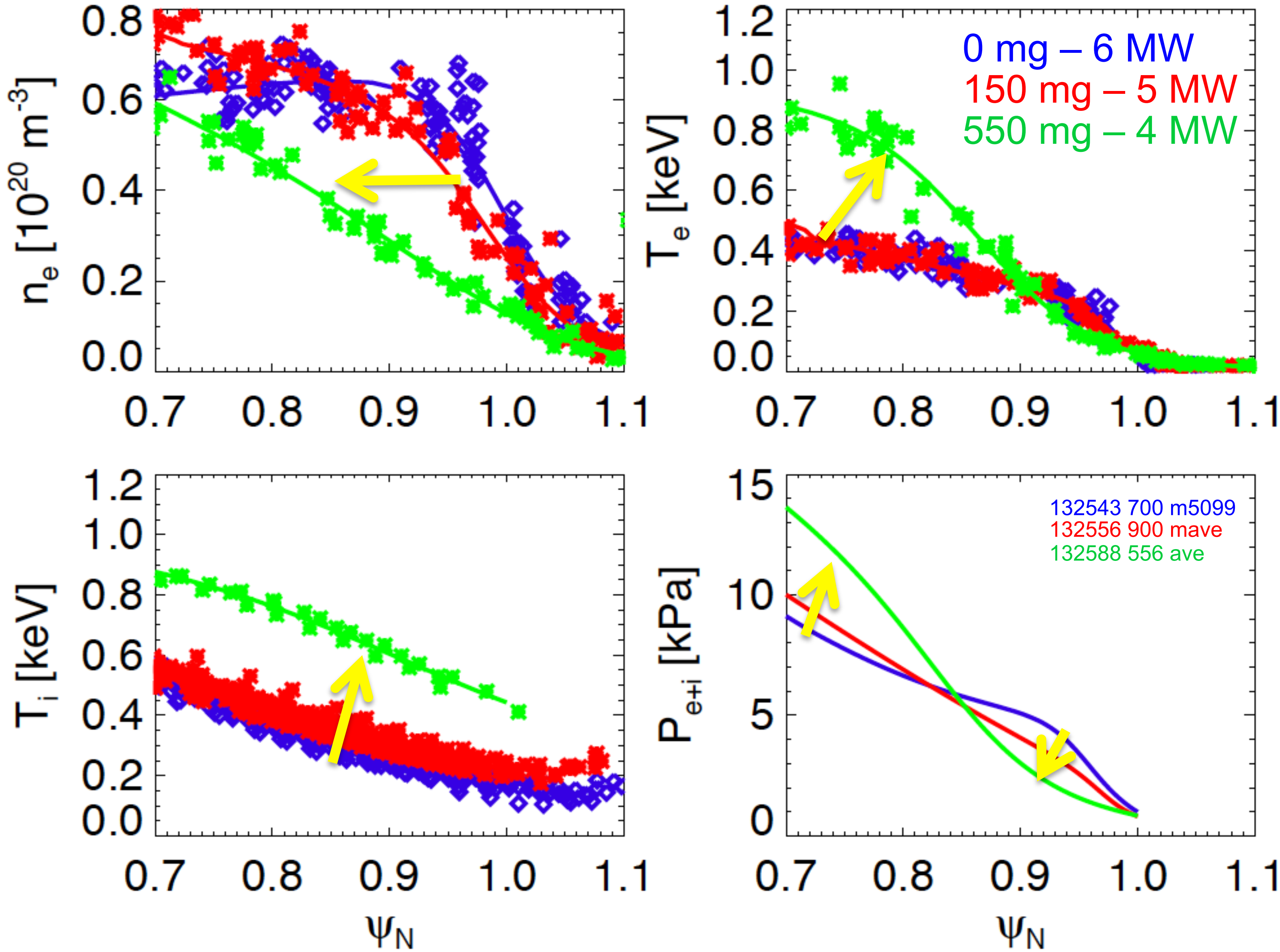
- 5x drop in D_α drop because of transition from high recycling to low recycling
  - Partial detachment in highly shaped no-Li discharges?

- <u>Possible geometric effect</u>: 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

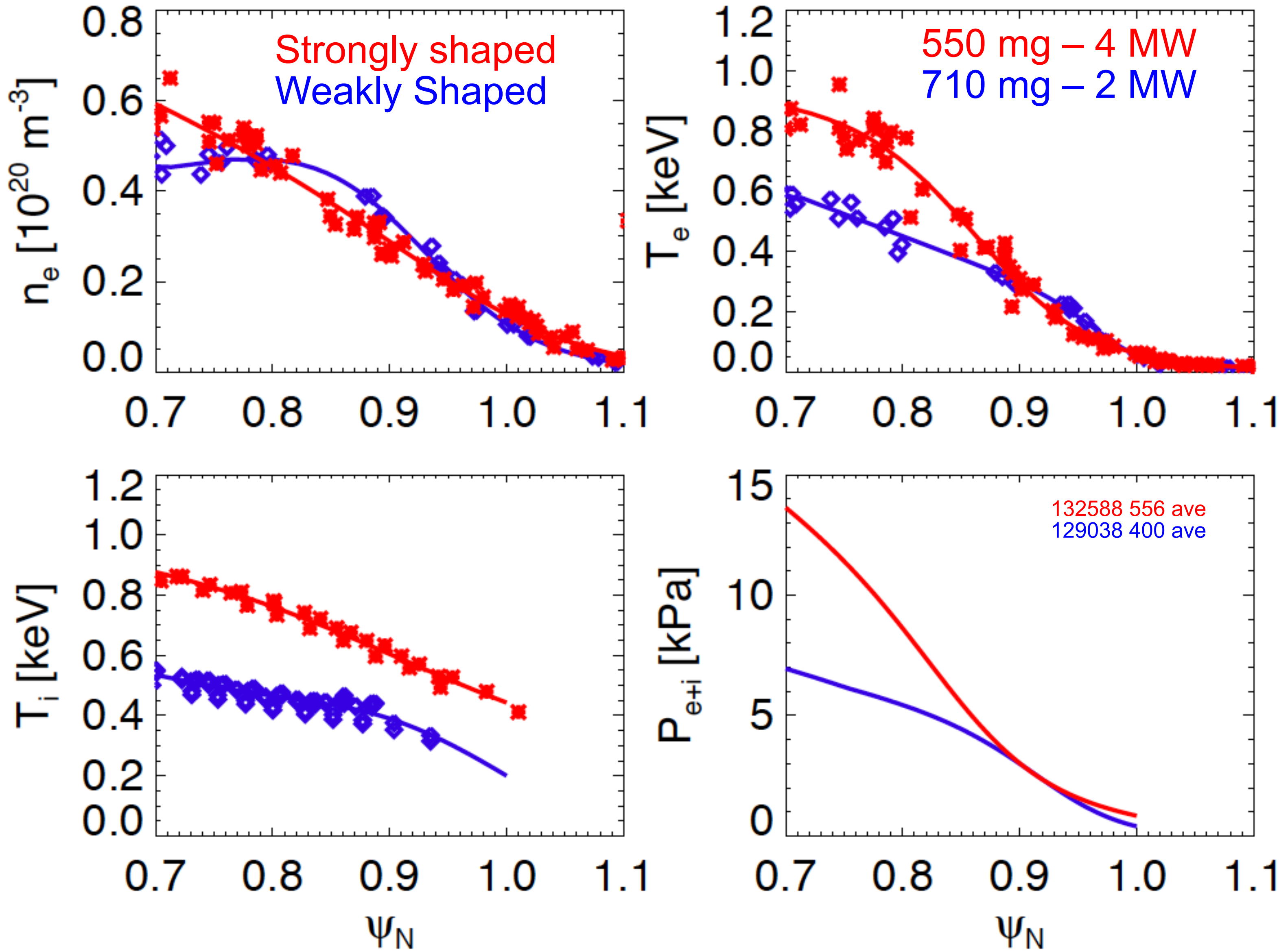
D_α and neutral pressure decreased, and H97L increased with increasing pre-discharge lithium evaporation in all data



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



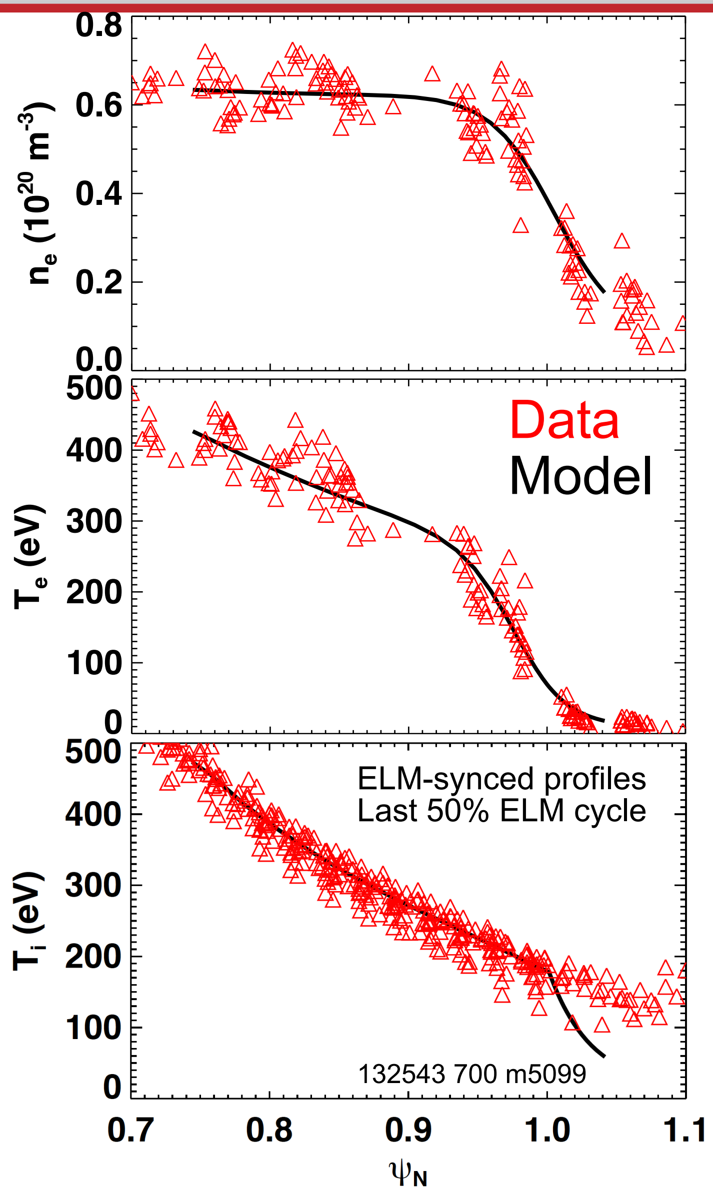
Higher NBI power in strongly shaped discharges leads to high edge temperature and pressure

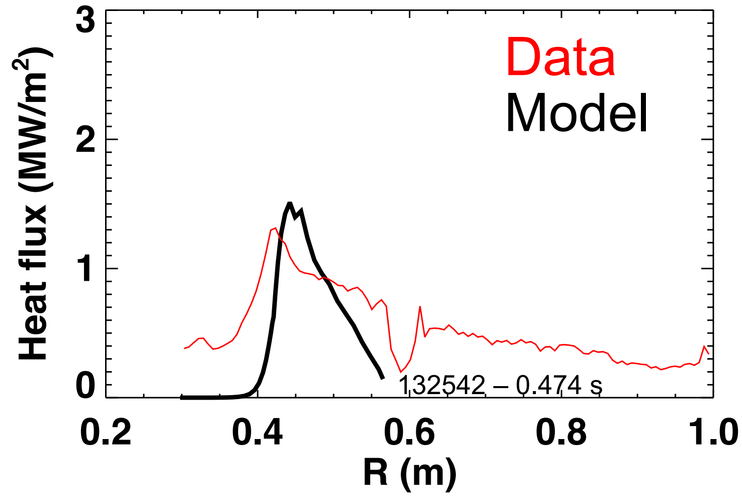


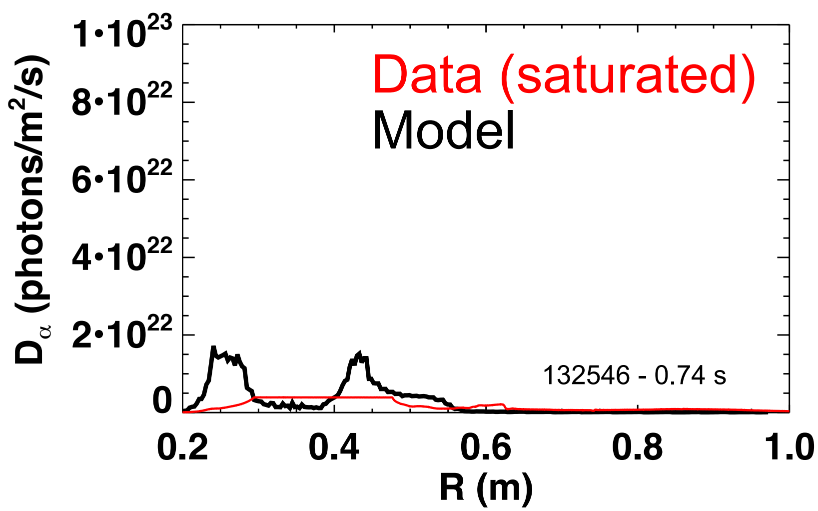
Goal of SOLPS interpretive analysis is to assess recycling coefficient and radial transport changes with lithium

- 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

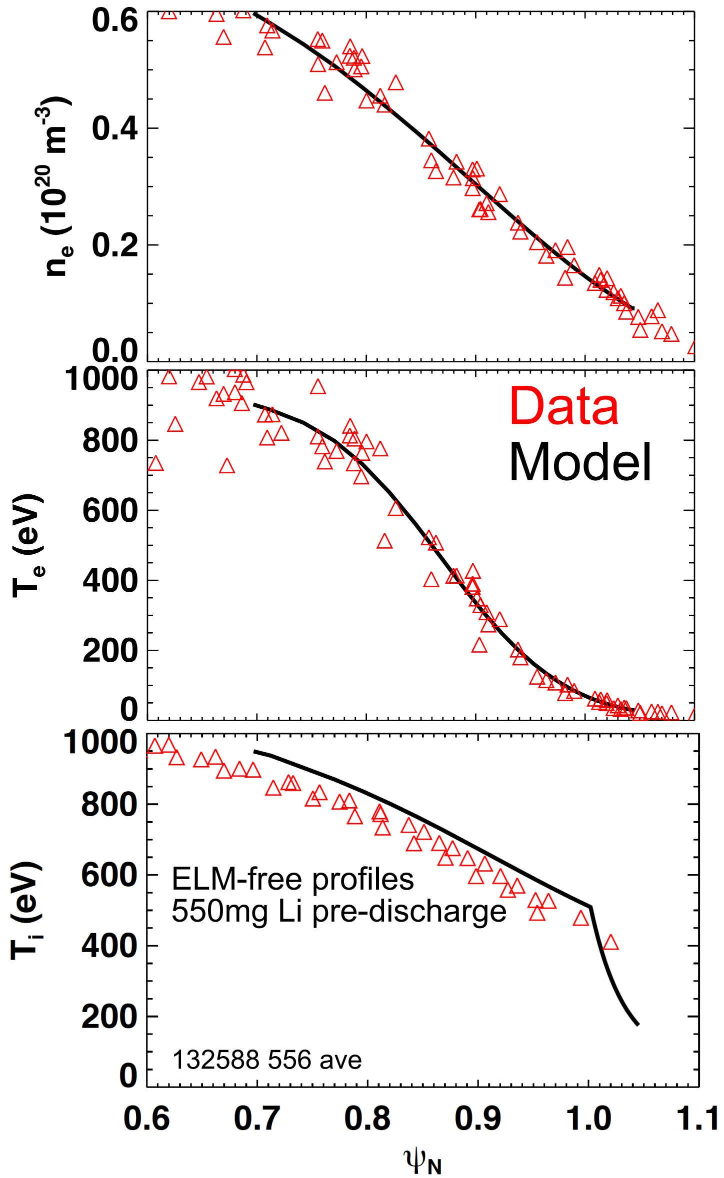


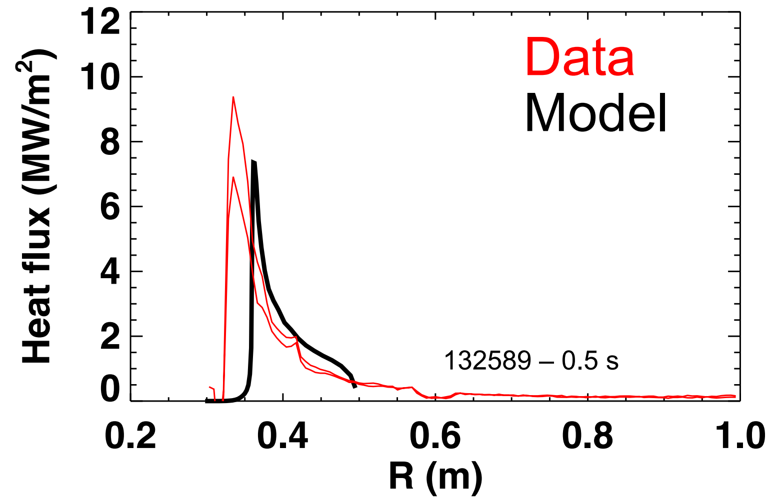


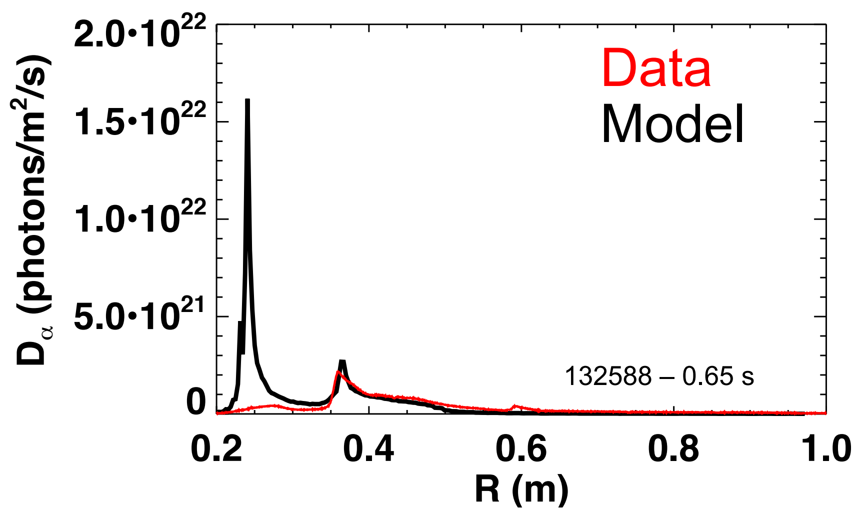


* D_α saturated from R=0.3-0.47m

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

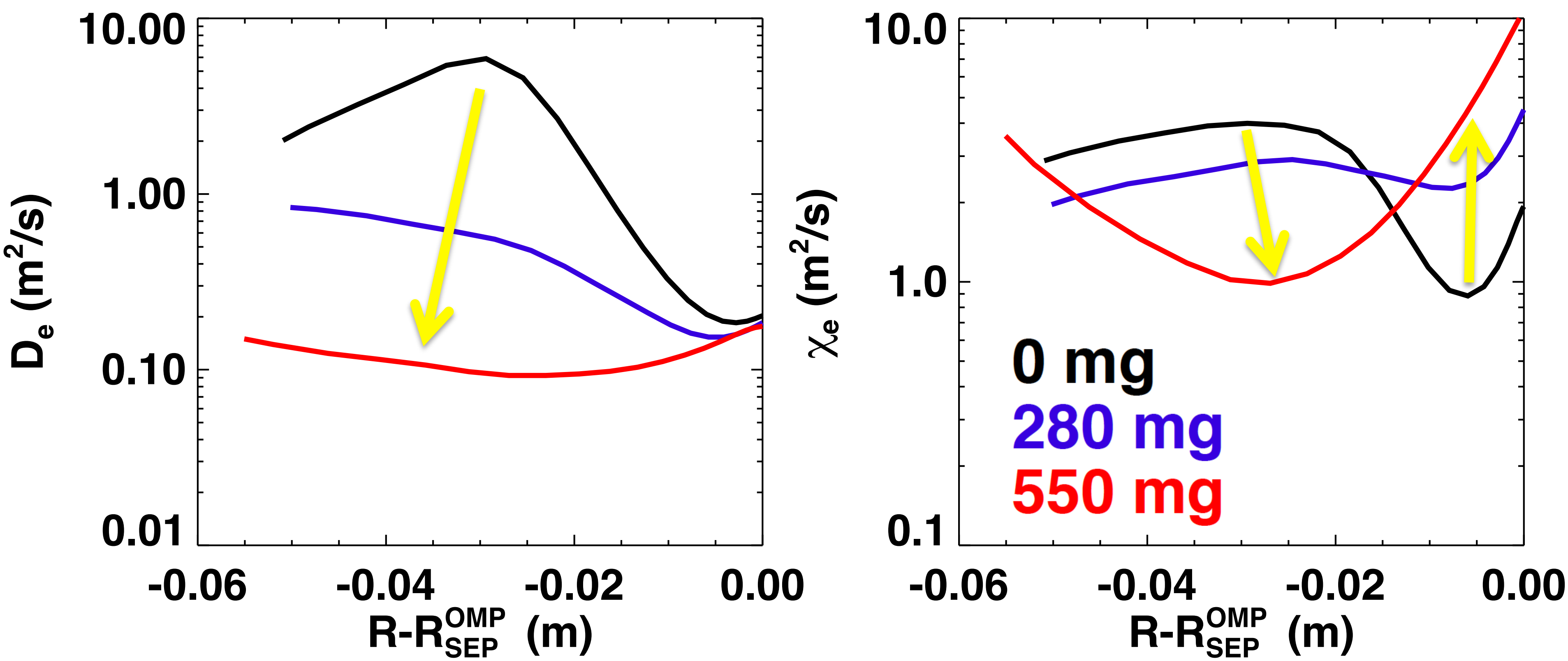






* Uncertainty in peak heat flux due to lithium use, no dual-band adapter

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

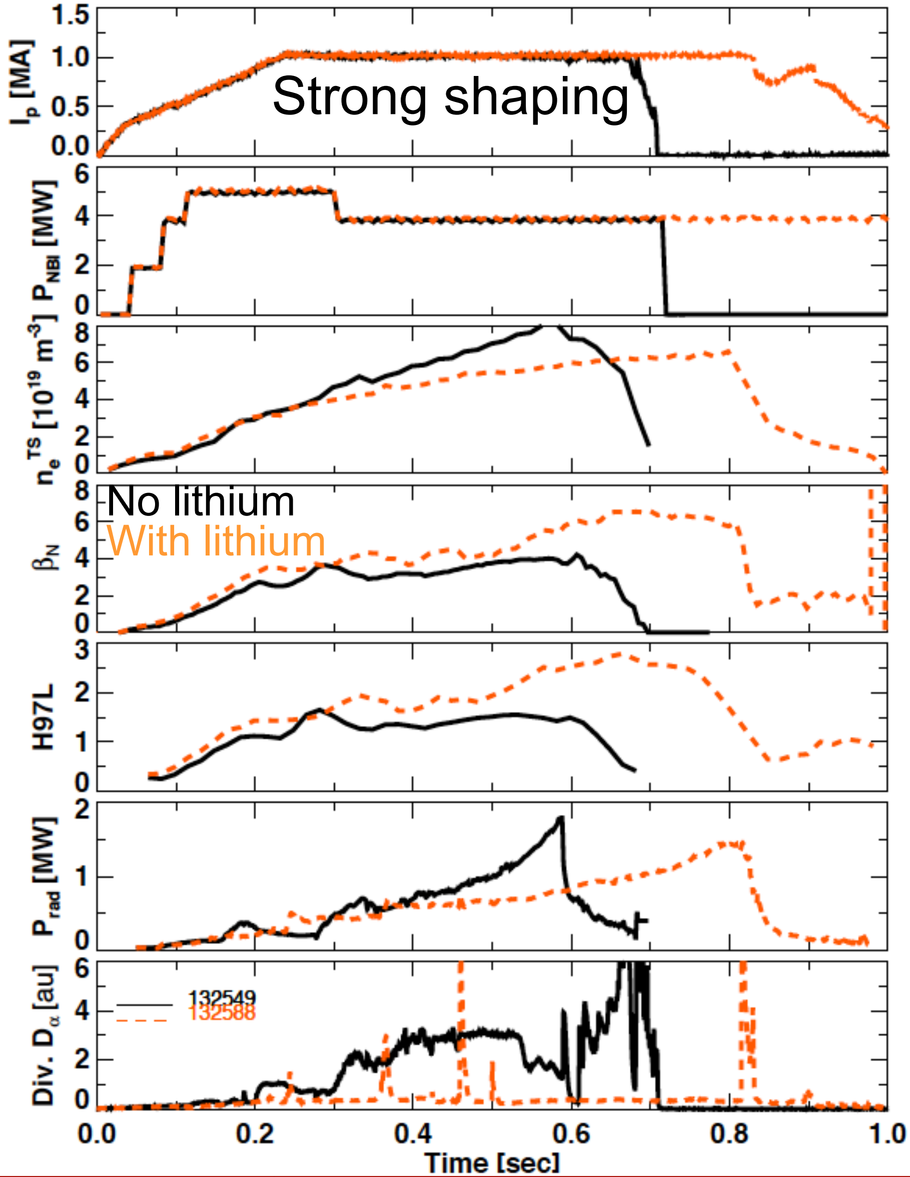
Lithium delivery tools being developed for NSTX-U

- Downward facing evaporators ~ Feb. 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) ~ 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!**

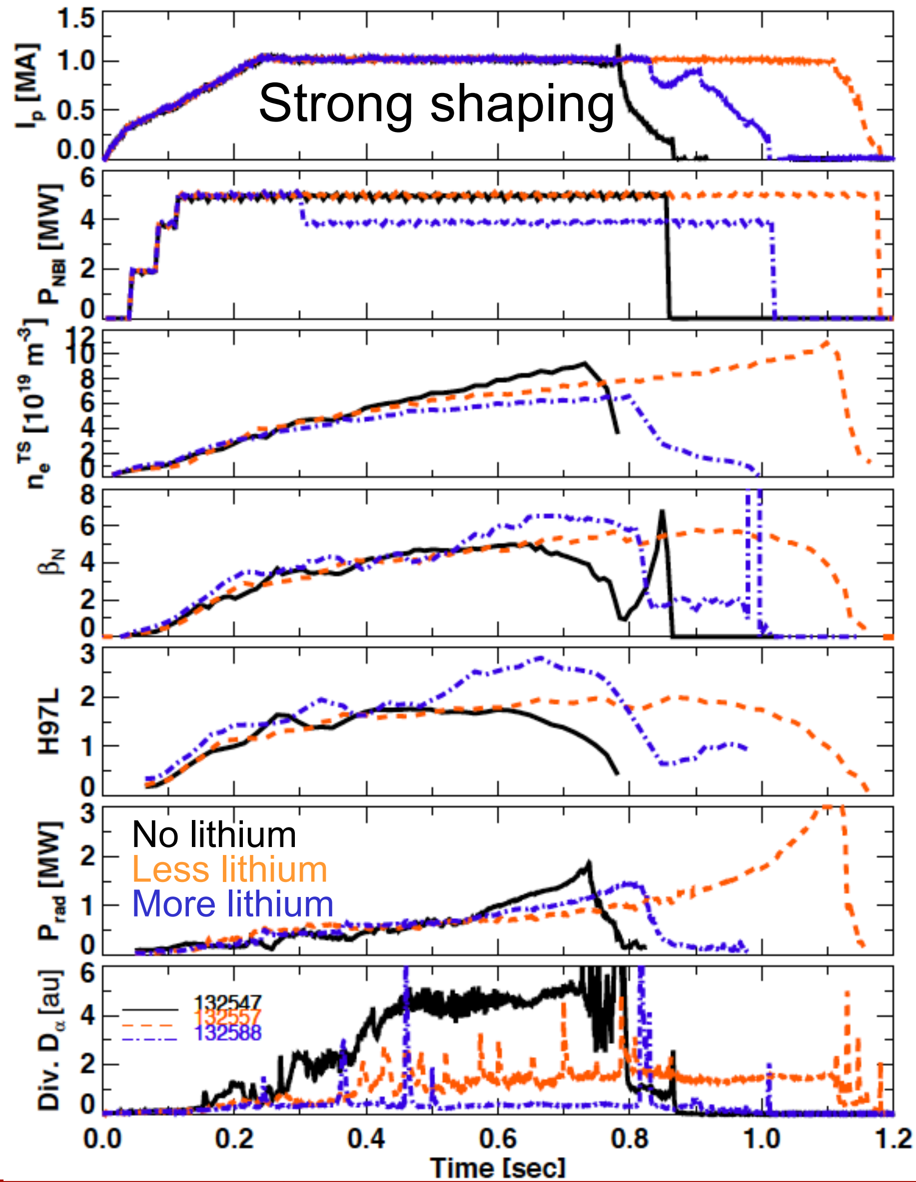
Poster Copies

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



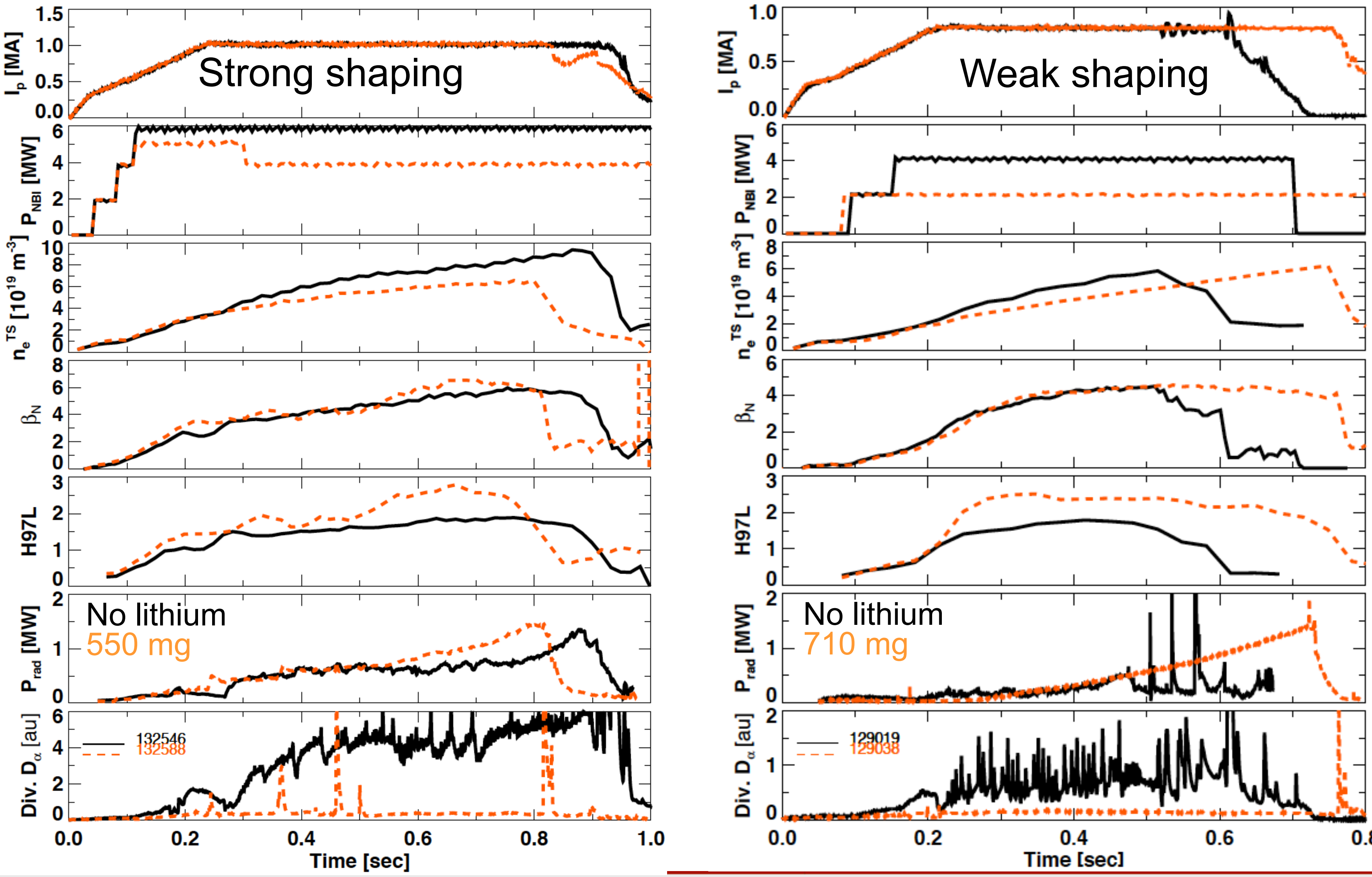
- Duration extended
- Same P_{NBI}
- Reduced dN/dt
- Higher stored energy
- Higher confinement
- Increasing P_{rad}
- Reduced recycling, long ELM-free phases

Similar effects on discharges observed with 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

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



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)