Measurements and 2-D Modeling of Recycling and Edge Transport in Discharges with Lithium-coated PFCs in NSTX

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

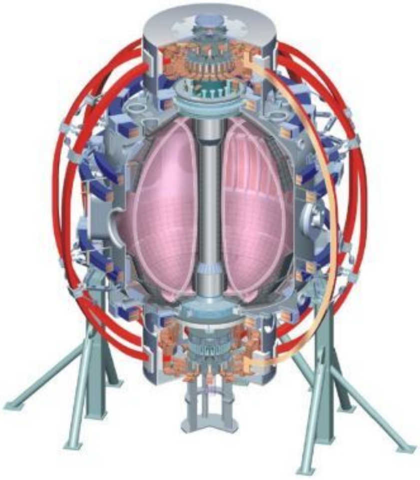
J.M. Canik

Oak Ridge National Laboratory

R. Maingi, J. Wilgen (ORNL), V.A. Soukhanovskii (LLNL), R.E. Bell, H.W. Kugel, B.P. LeBlanc (PPPL), S. Kubota (UCLA), T.H Osborne (GA)

and the NSTX Research Team

19th International Conference on Plasma Surface Interactions
San Diego, CA
May 24, 2010



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

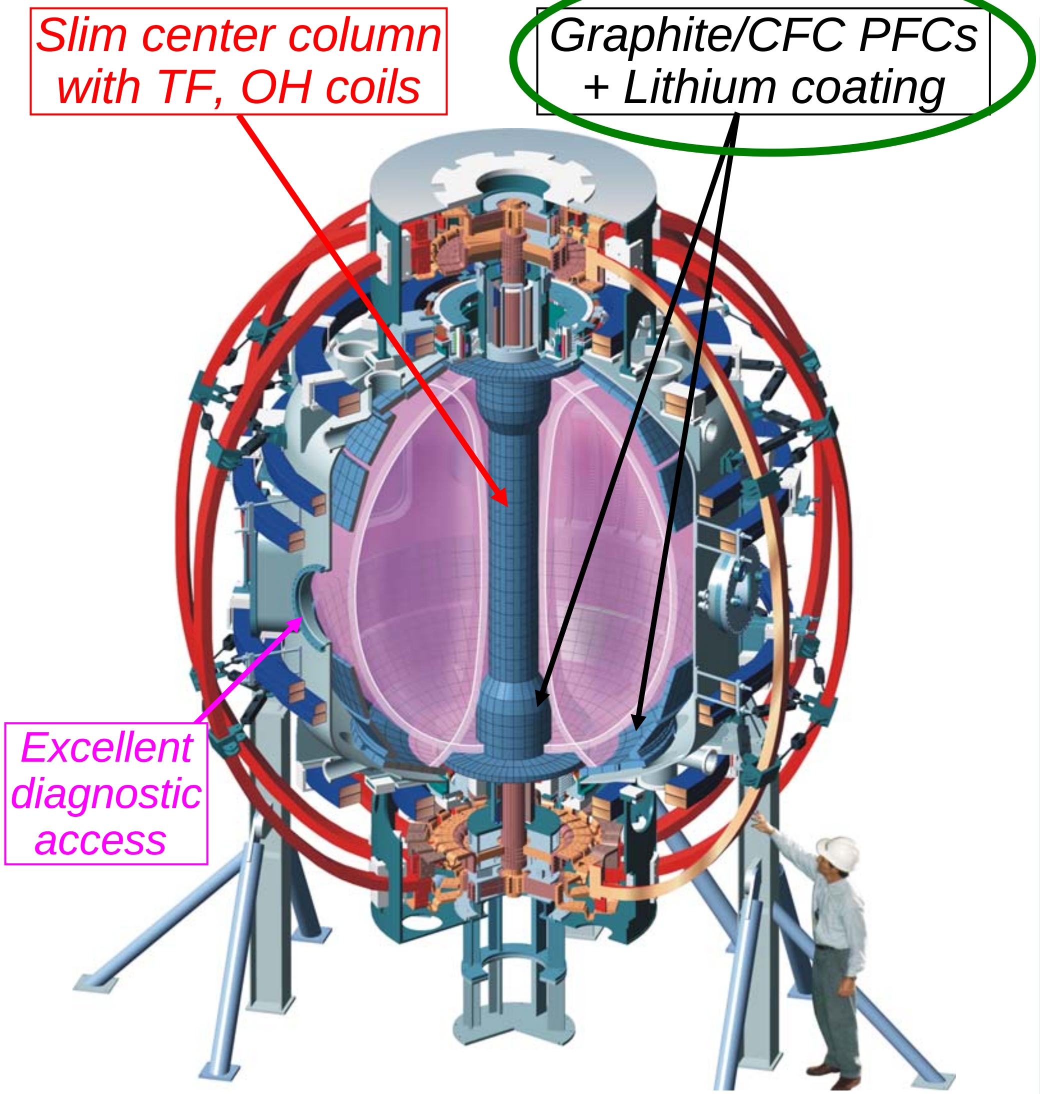
Outline

- Introduction to NSTX and overview of effects of lithium coatings on PFCs

- Measured pedestal profile changes with lithium

- 2-D edge modeling of pre- and post-lithium discharges shows
  - Reduced recycling coefficient
  - Widening of edge transport barrier

NSTX Facility Capabilities



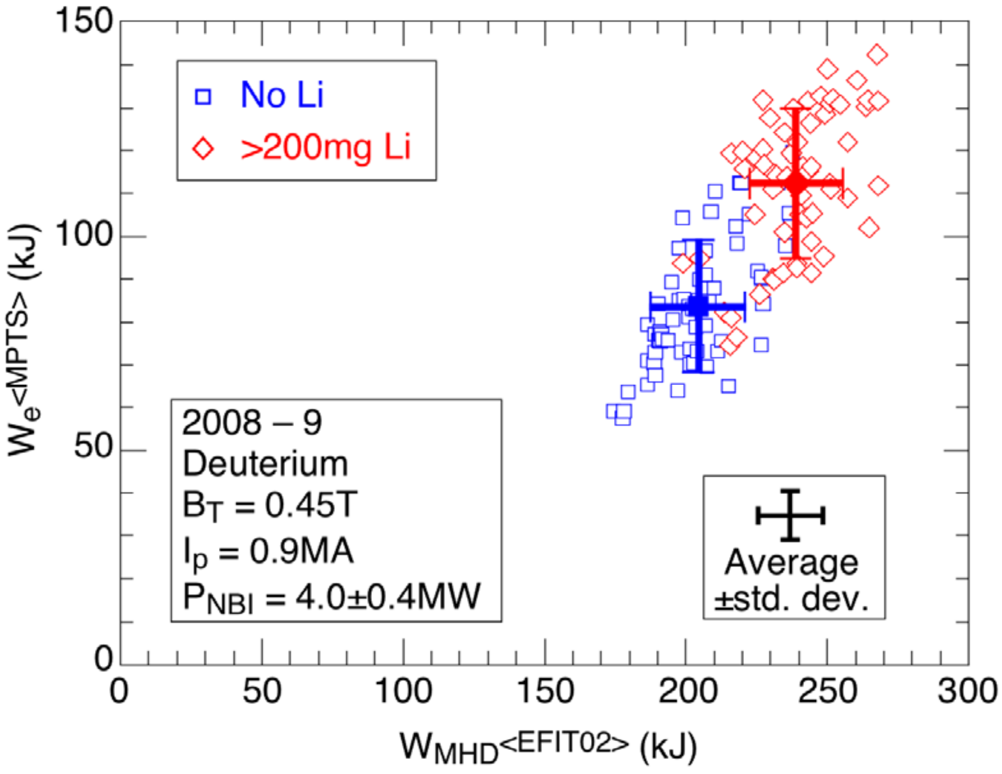
Slim center column with TF, OH coils

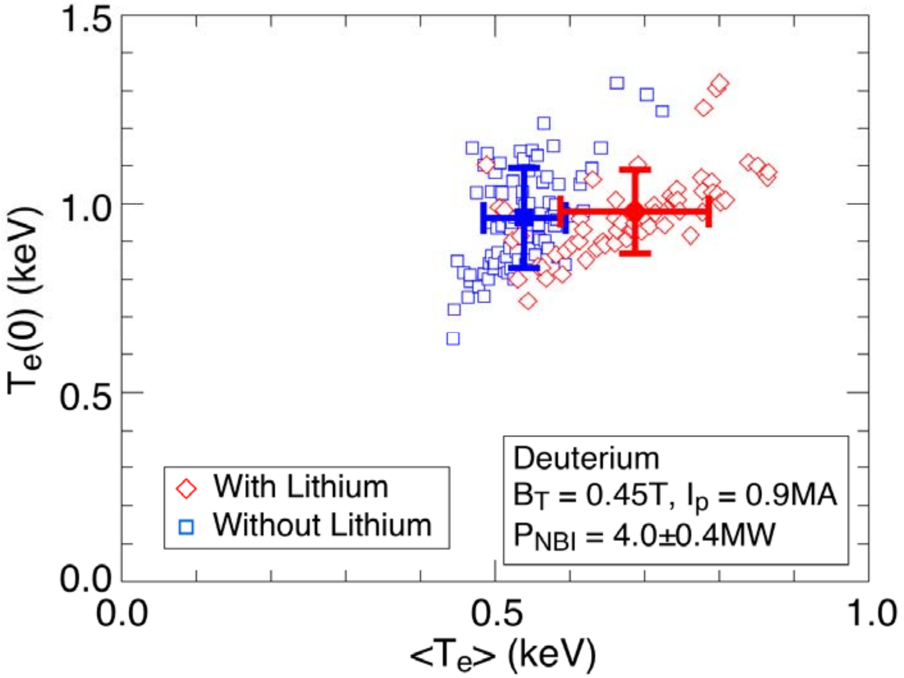
Graphite/CFC PFCs + Lithium coating

Excellent diagnostic access

R, a_{max}	0.85, 0.67 m
Aspect ratio A	1.27 – 1.6
Elongation κ	1.6 – 3.0
Triangularity δ	0.3 – 0.8
Toroidal Field B_{T0}	0.3 – 0.55 T
Plasma Current I_p	≤ 1.5 MA
Auxiliary heating:	
NBI (100kV)	≤ 7.4 MW
RF (30MHz)	≤ 6 MW
Central temperature	1 – 6 keV
Central density	$\leq 1.2 \times 10^{20} m^{-3}$

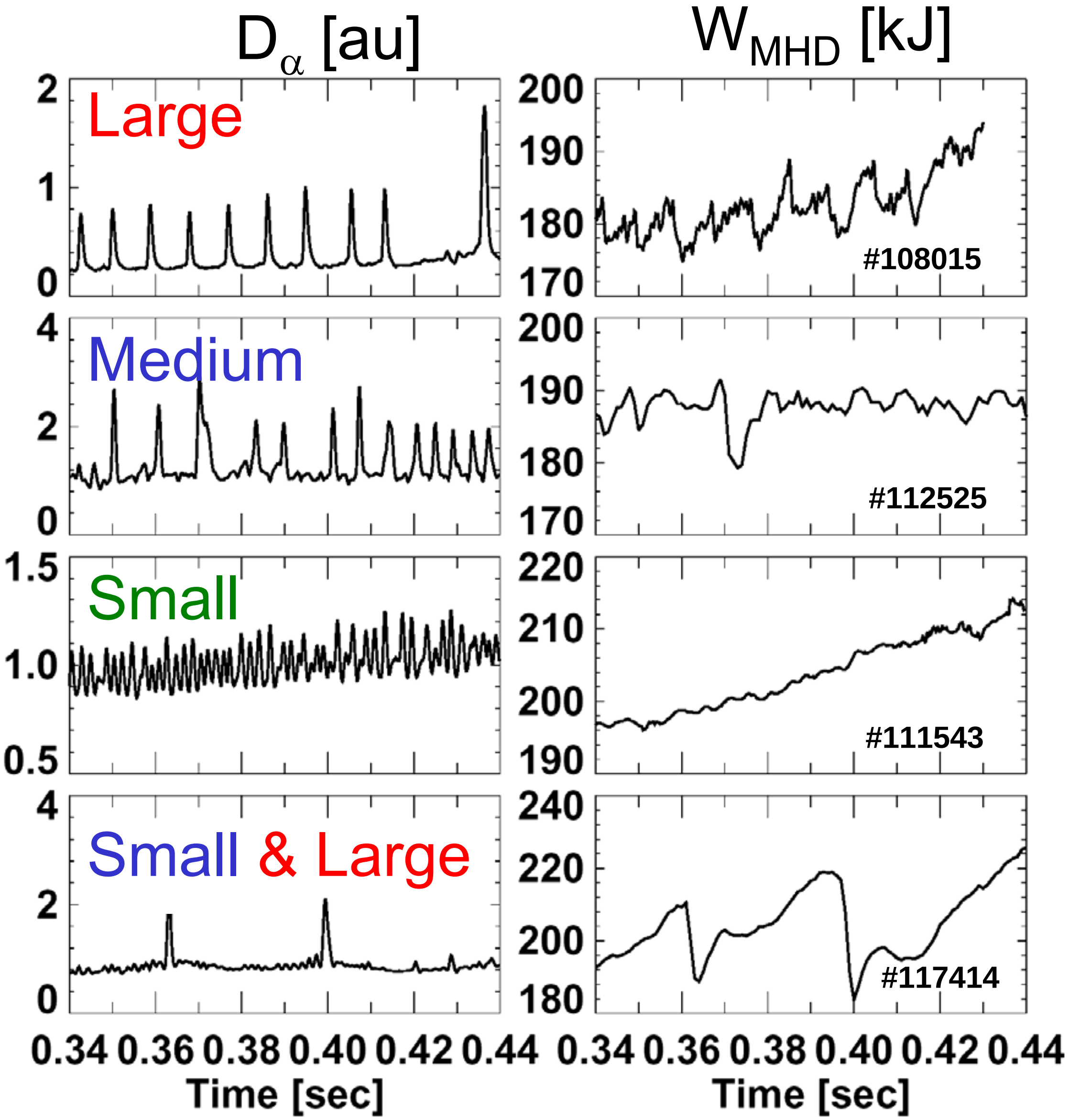
Confinement improves with lithium coatings, due to broadening of the electron temperature profiles





M. Bell EPS09, S. Ding PPCF at press

Edge localized modes (ELMs) observed in many non-lithium NSTX H-mode discharges



$\Delta W_{MHD}/W_{MHD} \sim$ 3-20%

$\Delta W_{MHD}/W_{MHD} \sim$ 1-5%

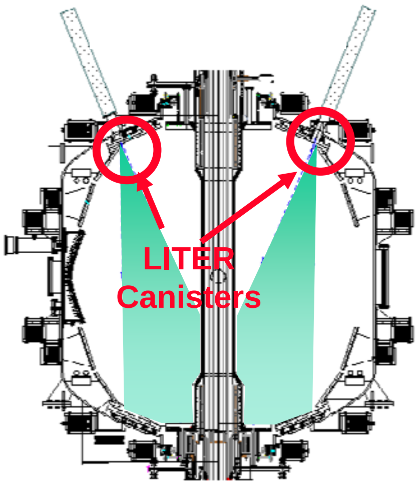
$\Delta W_{MHD}/W_{MHD} \leq$ 1%

$\Delta W_{MHD}/W_{MHD} \leq$ 30%

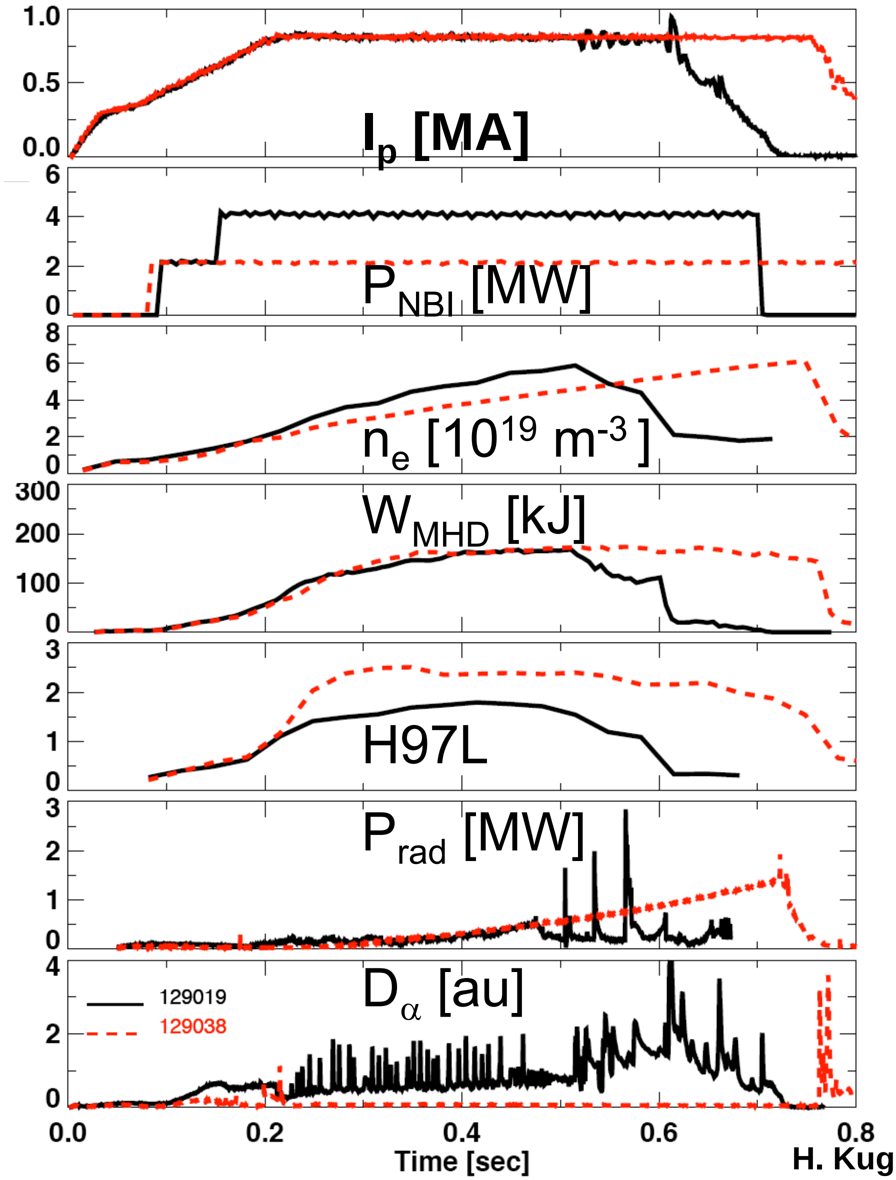
R. Maingi, JNM 2005

ELM-free H-mode induced by lithium wall coatings

Predicted* by
L. Zakharov
in 2005



~ 700mg Li
before 129038

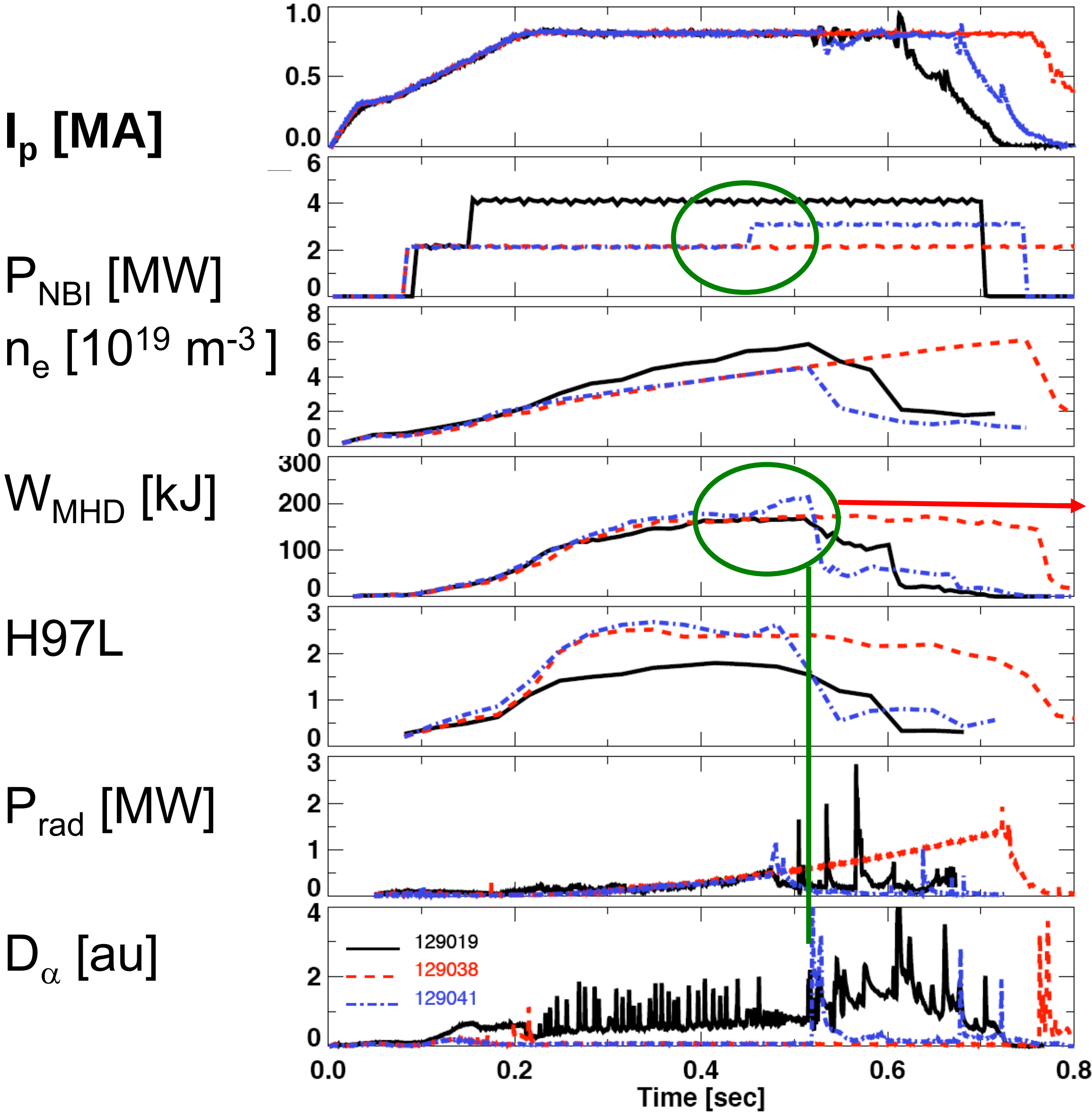


- Pre-Li, Post-Li
- Lower NBI to avoid β limit
- Lower n_e
- Similar stored energy
- H-factor 40%↑
- Higher P_{rad} /P_{heat}
- ELM-free, reduced divertor recycling

H. Kugel PoP 2008, R. Kaita IAEA 2008

*** L. Zakharov, JNM 2007**

Global β_N limit encountered before edge stability limit with lithium coatings

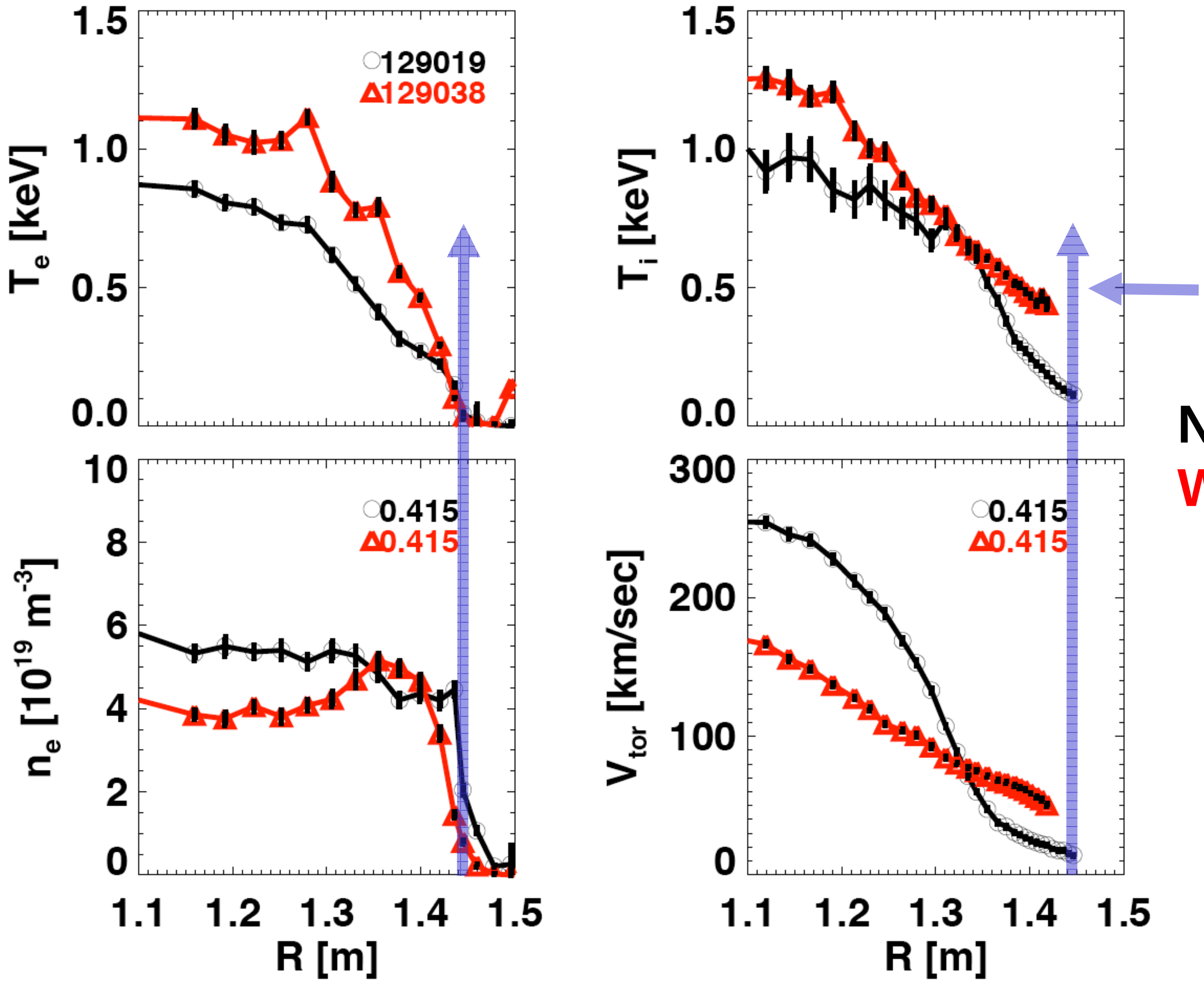


- Pre-Li, Post-li, Post-li at β limit
- Intermediate NBI to probe β limit

β_N limit ~ 5.5 with P_{NBI}=3 MW

R. Maingi, PRL 2009

T_e, T_i increased and edge n_e decreased with lithium coatings

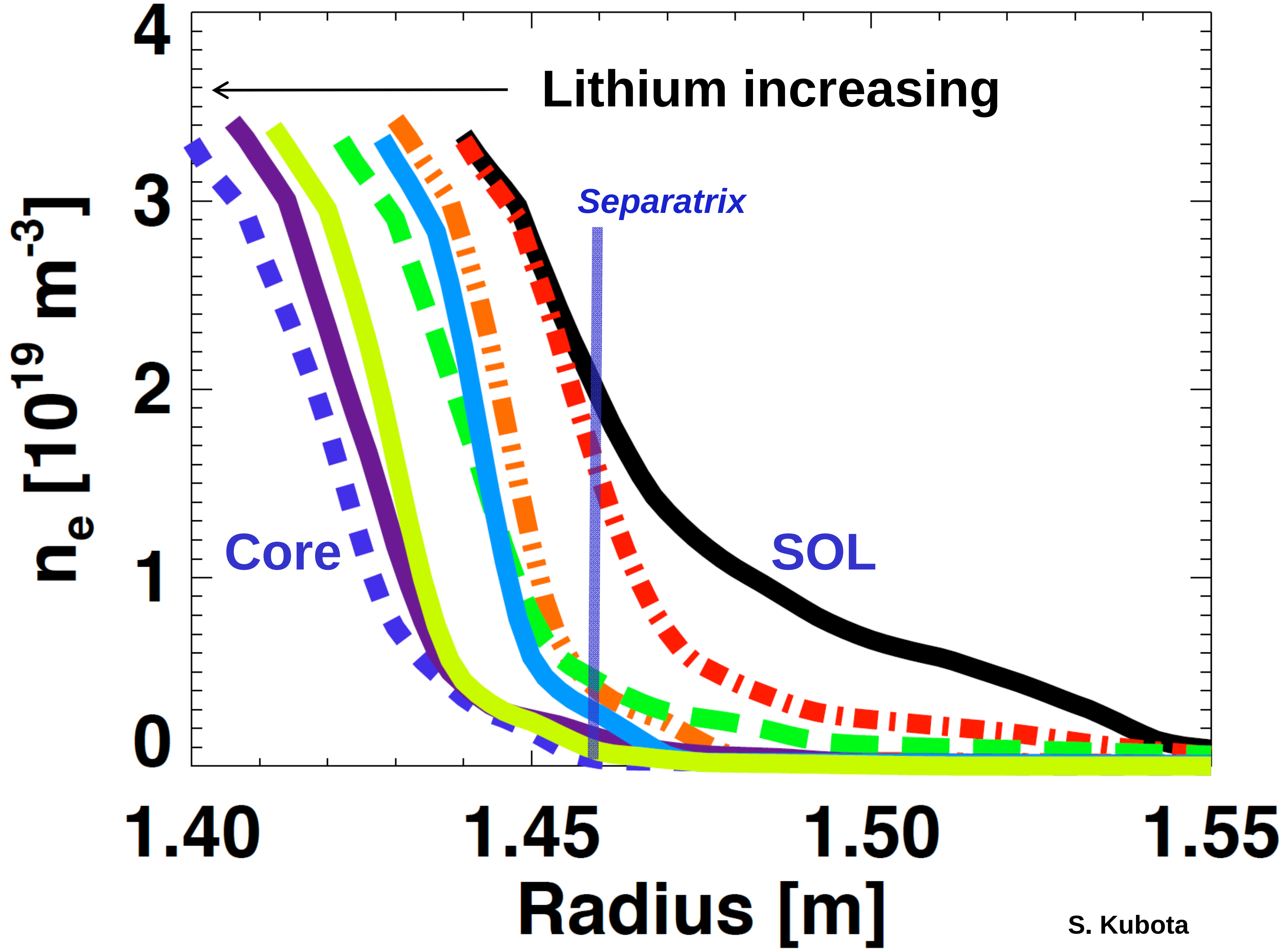


separatrix

No lithium

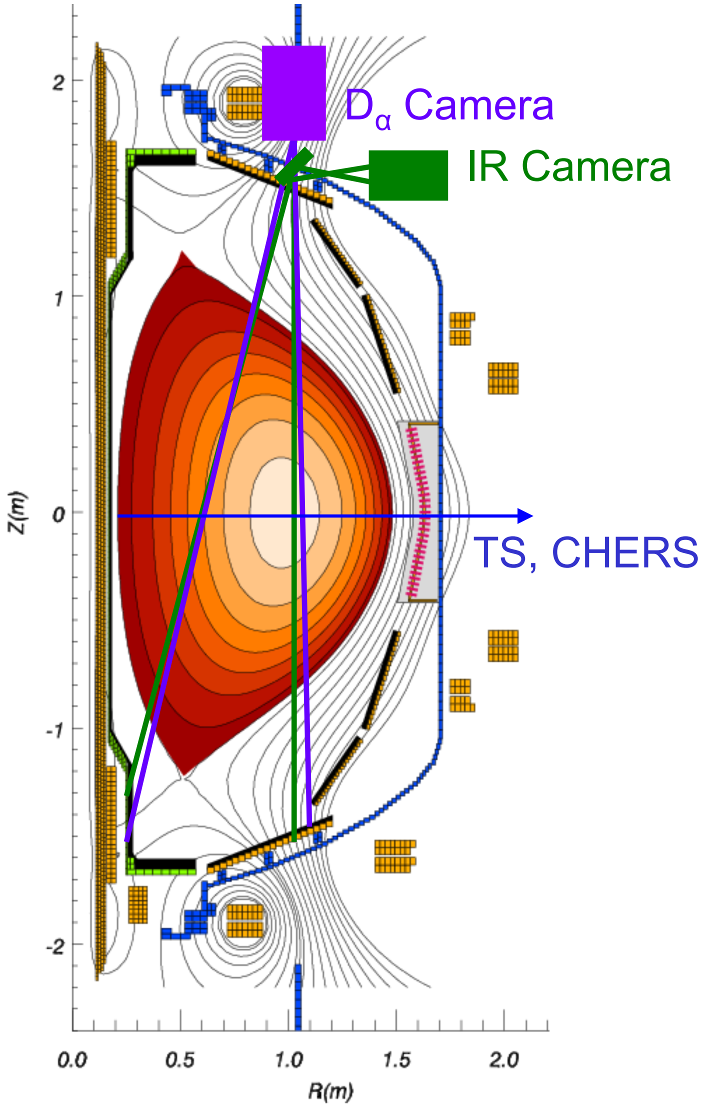
With lithium

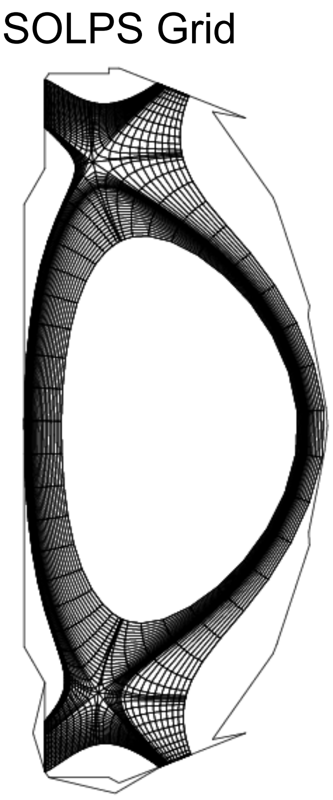
Density profile shifted inward near the magnetic separatrix



S. Kubota

Pre- and post-lithium discharges are modeled using SOLPS

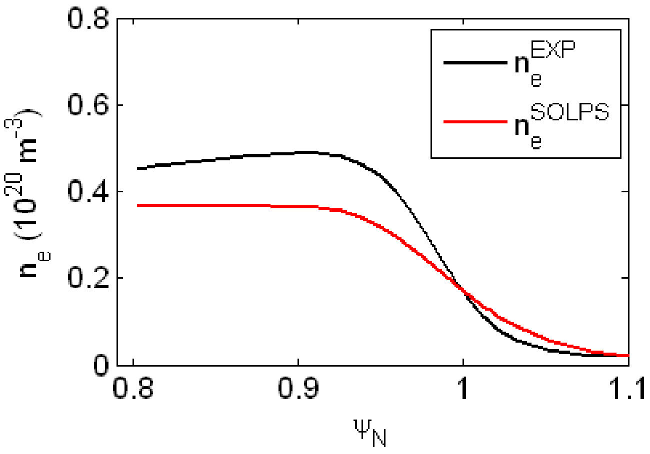


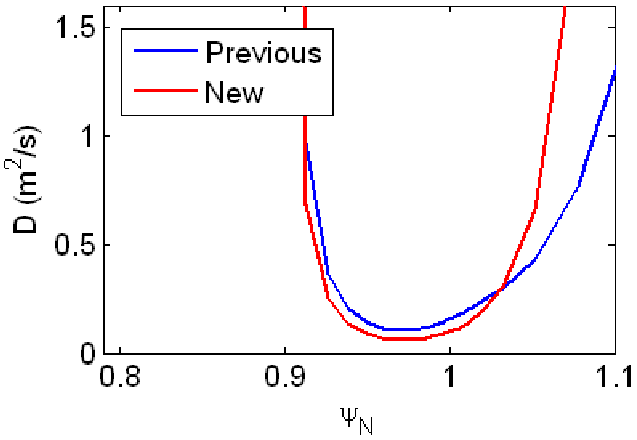


- SOLPS (B2-EIRENE: 2D fluid plasma + MC neutrals) used to model NSTX experimental data
  - Density, electron and ion temperatures taken from fits to measurements, along with IR measurements of the heat flux
  - Transport coefficients adjusted to give match to n_e,T_e,T_i
  - Since separatrix location is uncertain, profiles are shifted in/out to give fit to heat flux measurements

Procedure for fitting midplane n_e, T_e, T_i profiles

- Start with initial guess for $D_\perp$, χ_e,χ_i
- Run simulation nearly to convergence
- Take radial fluxes along 1-D slice at midplane from code
  - Γ^{SOLPS}, q_e^{SOLPS}, q_i^{SOLPS}
- Calculate new transport coefficients using SOLPS fluxes and *experimental* profiles
  - E.g., $D^{new} = - \Gamma^{SOLPS}/grad(n_e^{EXP})$
  - If SOLPS fluxes remain fixed, would result in code profiles matching experiment
  - Here we use fits to profiles used in stability calculations (Maingi PRL '09)
- Repeat until $n_e/T_e/T_i^{SOLPS} \sim n_e/T_e/T_i^{EXP}$
- During this process, experimental profiles are shifted slightly relative to the separatrix so that peak heat flux from code matched peak measured value from IR cam

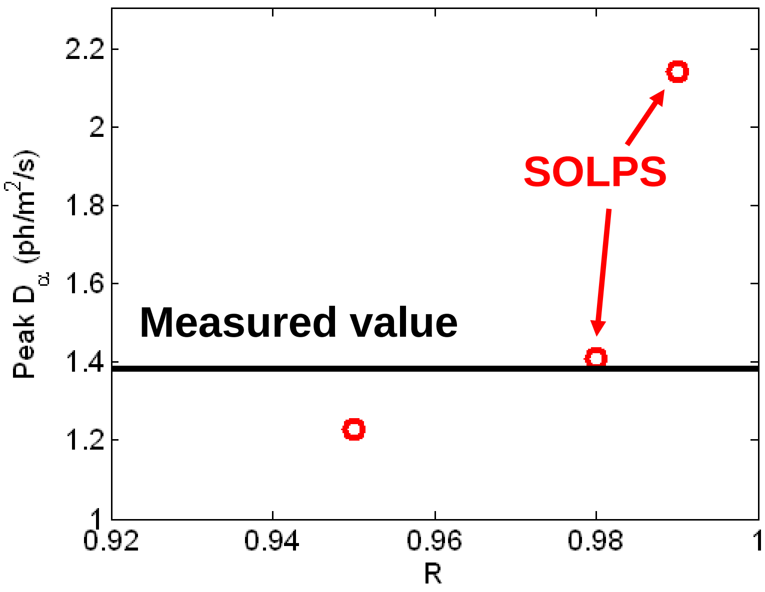




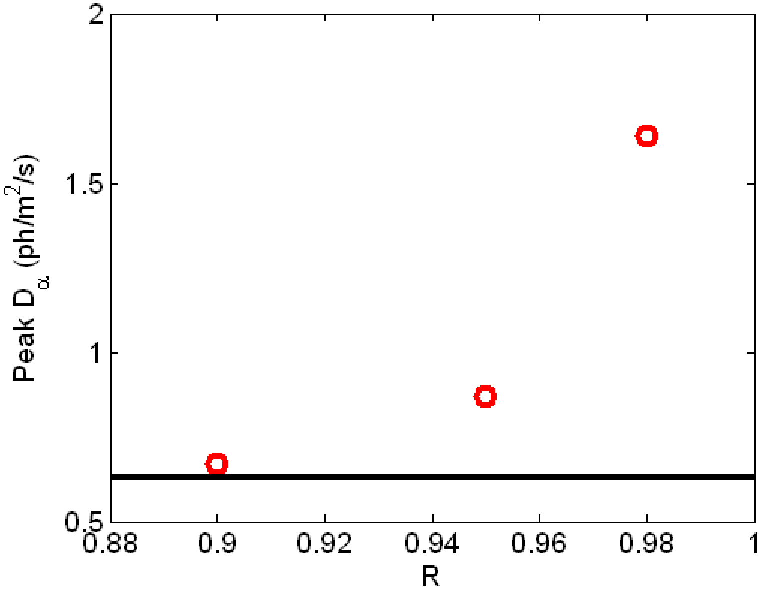
Peak D_α brightness is matched to experiment to constrain PFC recycling coefficient: lithium reduces R from ~.98 to ~.9

- For each discharge modeled, fits are done using varying values of R at the target plates
  - Transport is *not* fixed during this scan, fits to midplane data are redone at each R to maintain match to experiment
- D_α emissivity from code is integrated along LOS of camera, compared to measured values
  - Best fit indicates reduction of recycling from R~0.98 to R~0.9 when lithium coatings are applied

Pre-lithium



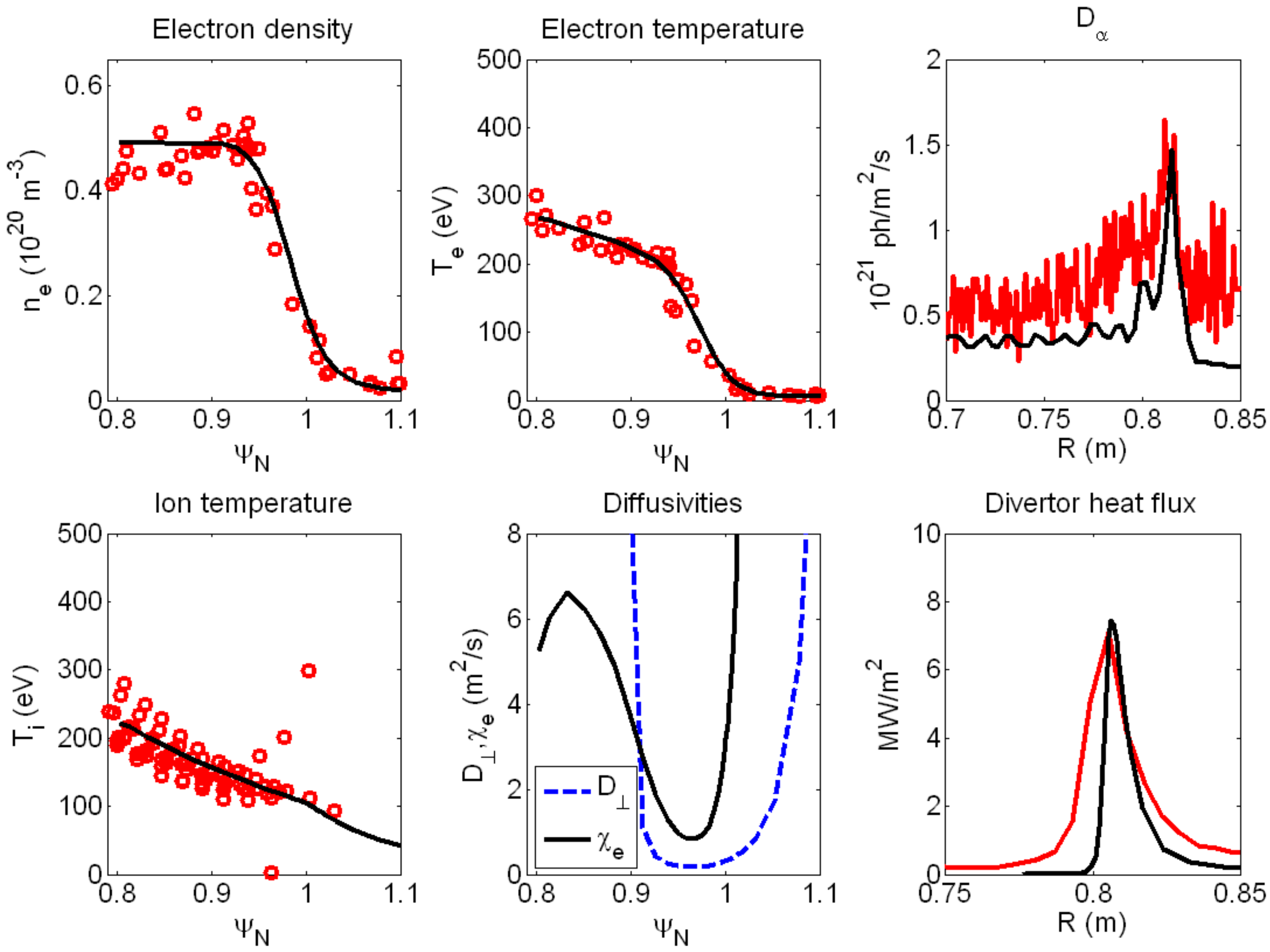
Post-lithium



Midplane and divertor profiles from modeling compare well to experiment for the pre-lithium case

- P=3.7 MW
- R=0.98

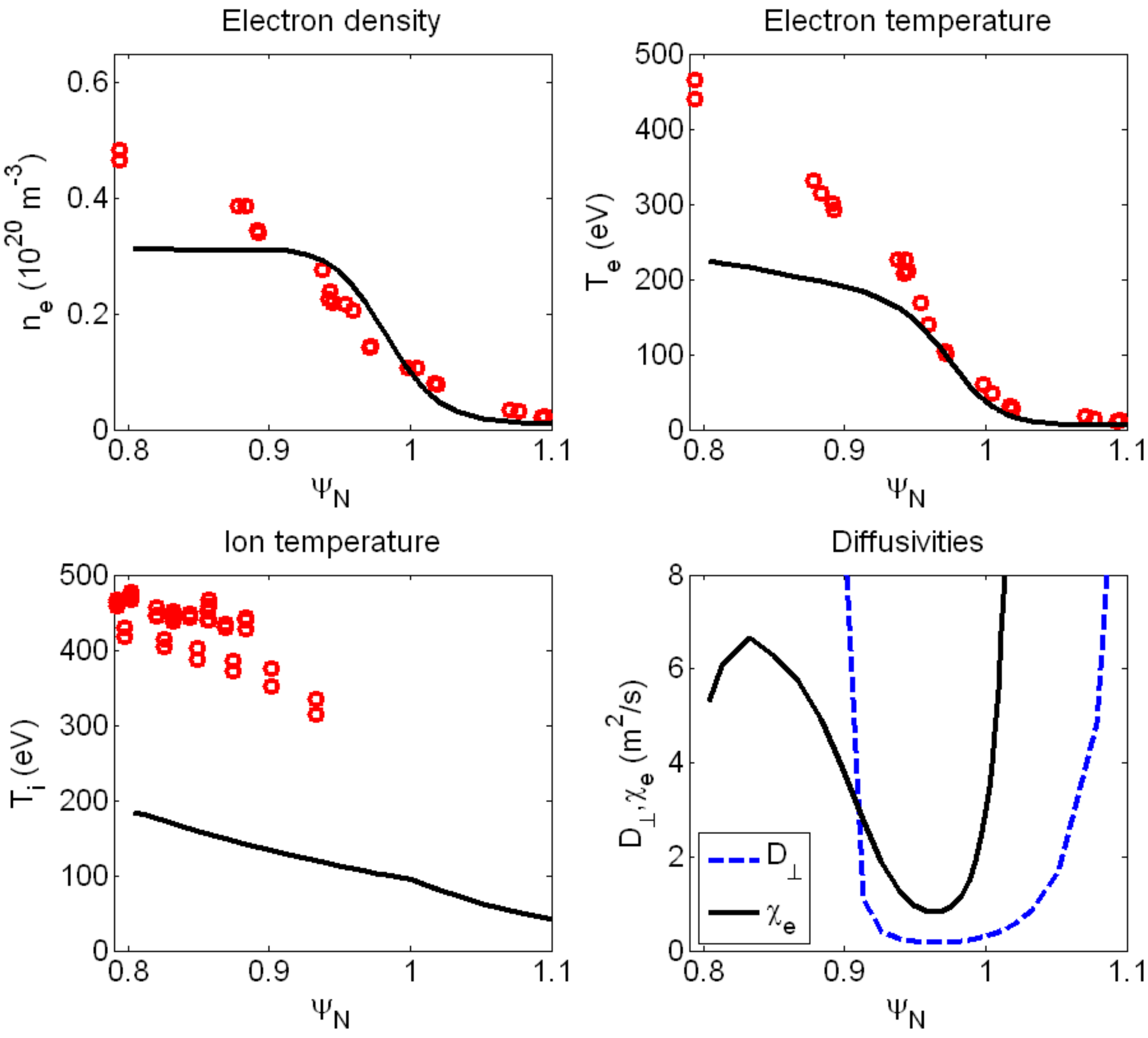
- Good match to midplane profiles
- Heat flux and D_α profiles shifted radially to align peaks (uncertainty in reconstructed R_{OSP})
- Peak heat flux and D_α matched, but radial decay sharper than experiment
  - Poloidally dependent transport coefficients?



Reducing recycling coefficient alone is not sufficient to reproduce profile with lithium coated PFCs

- P=1.9 MW
- R=0.90

- Transport kept fixed from pre-lithium case
- To match conditions during discharge with lithium coatings:
  - Power reduced
  - Beam fuelling reduced
  - Gas puff increased
- R reduced to 0.9 to simulate lithium pumping
- Not enough to match experiment
  - Density simply reduced, shape change is not captured
  - Te and Ti underestimated inside $\psi_N \sim 0.95$



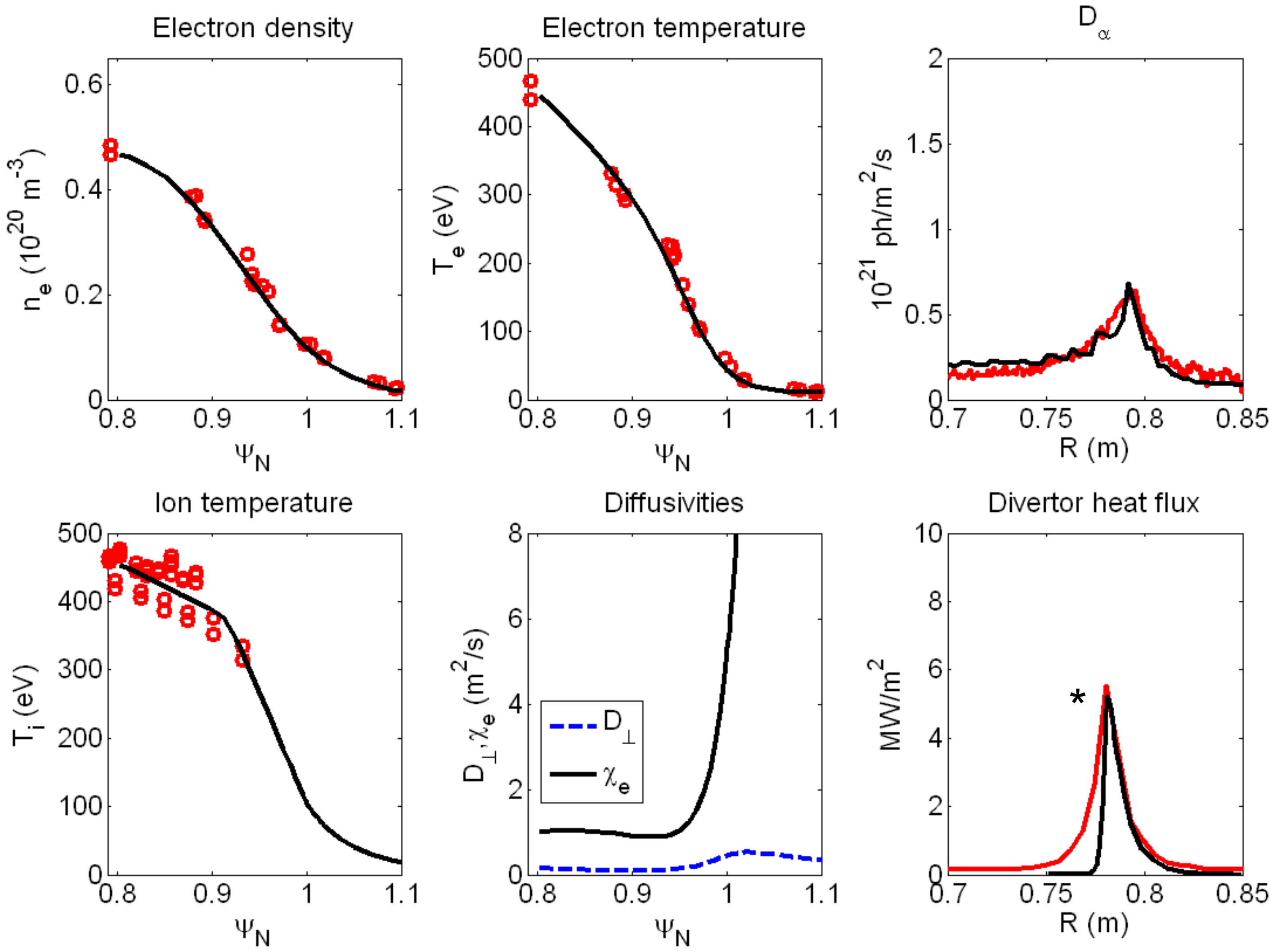
Combining reduced recycling and transport changes gives better match to experiment

- P=1.9 MW
- R=0.90

- Transport coefficients adjusted to recover fit to upstream data

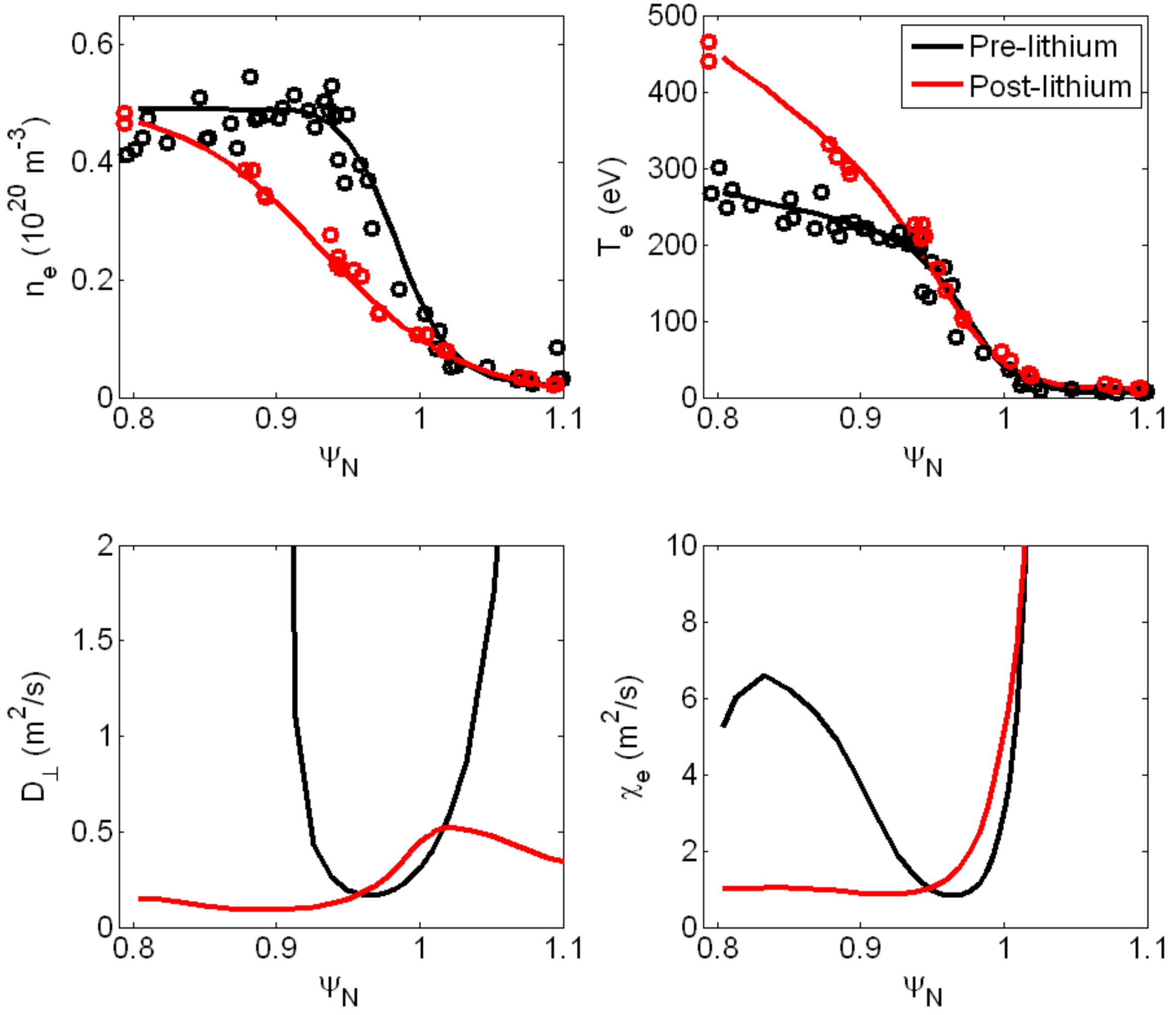
- Good match to both peak and profile for heat flux and D_α (except PFR)

*Uncertainty exists in IR measurements, due to emissivity change with lithium films



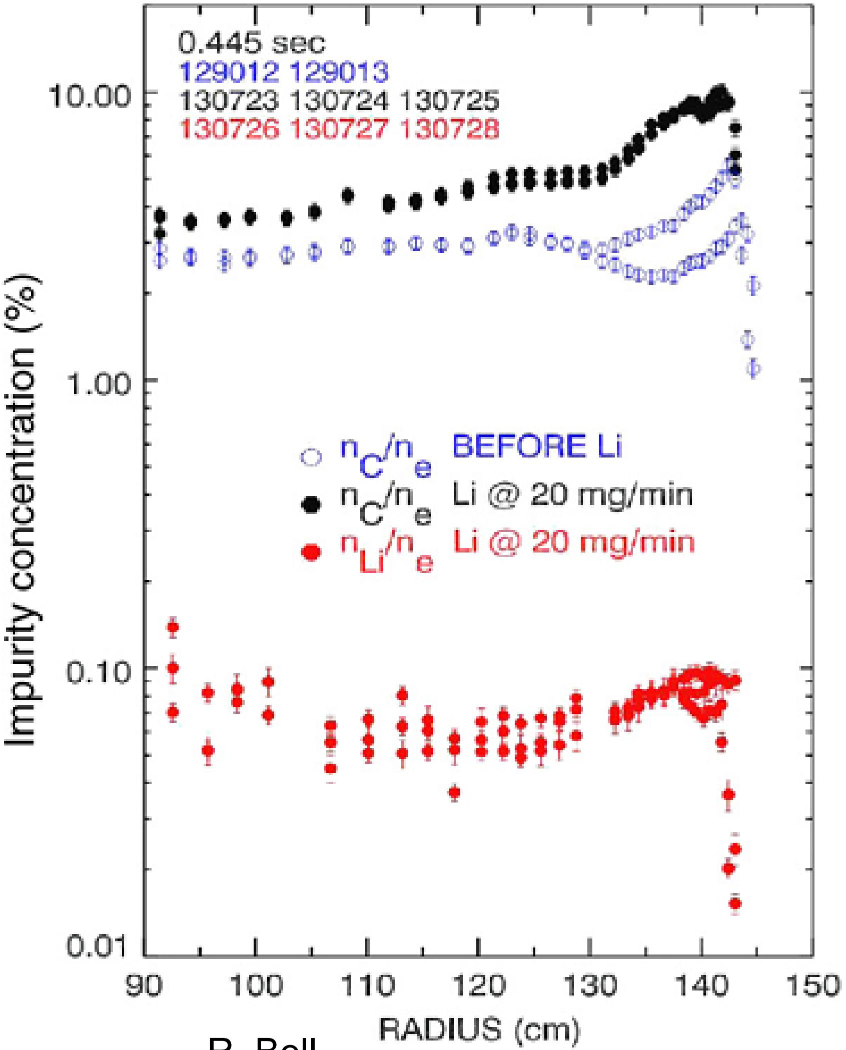
Transport barrier widens with lithium coatings, broadening pedestal

- Pre-lithium case shows typical H-mode structure
  - Well define “end” to the pedestal at ψ_N~0.95
  - Barrier region in D, χ_e just inside separatrix
- Pedestal is much wider with lithium
  - Pedestal top not clear from profiles
  - $D_\perp$, χ_e similar outside of ψ_N~0.95
  - Low $D_\perp$, χ_e persist to inner boundary of simulation (ψ_N~0.8)
- Changes to profiles with lithium are due to reduced fluxes combined with wide transport barrier



Carbon is the dominant impurity species with lithium coatings

- Measured lithium concentration is much less than carbon
  - Carbon concentration ~100 times higher
  - Carbon increases when lithium coatings are applied
  - Neoclassical effect: higher Z accumulates, low Z screened out
- Increase in n_C due to lack of ELMs
  - Can be mitigated by triggering ELMs



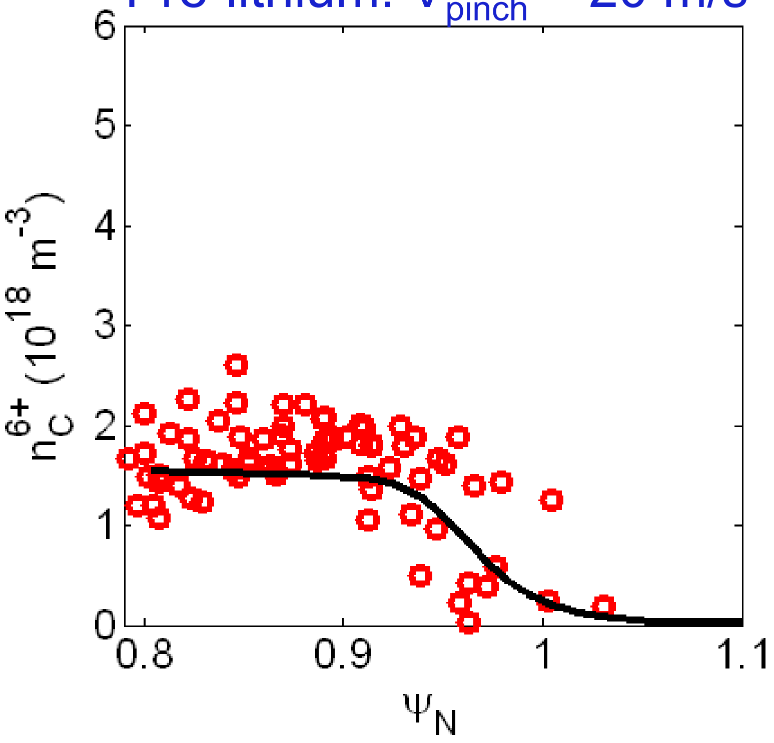
R. Bell

M. Bell, PPCF **51** (2009) 124054

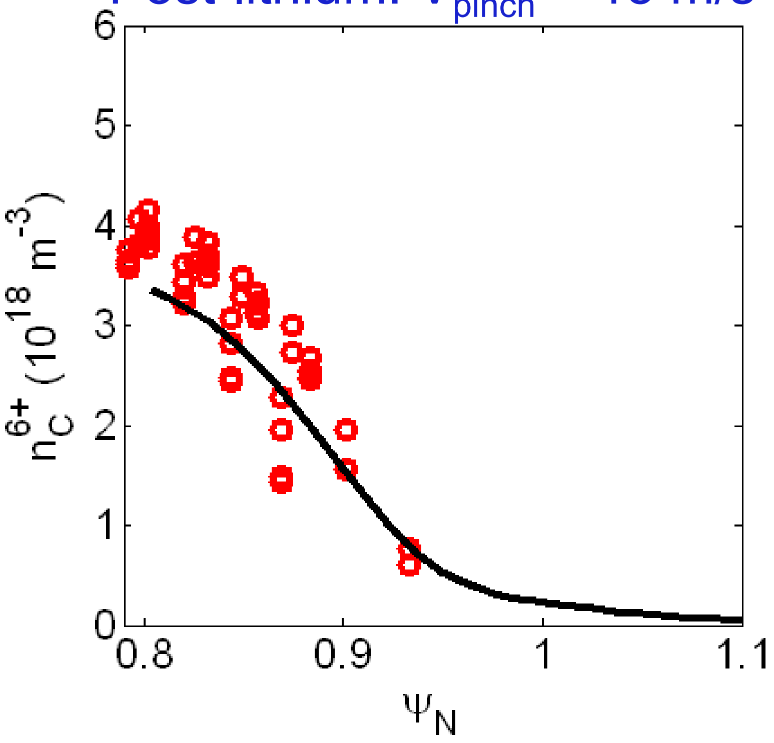
Including carbon sputtering, assuming constant pinch velocity reproduces edge C profiles

- Sputtering of carbon included, with constant chemical sputtering yield of 2% assumed
- Same $D_\perp$ for all species
- Carbon species given spatially constant inward convective velocity, adjusted to match measured carbon content

Pre-lithium: V_{pinch} = 20 m/s



Post-lithium: V_{pinch} = 15 m/s

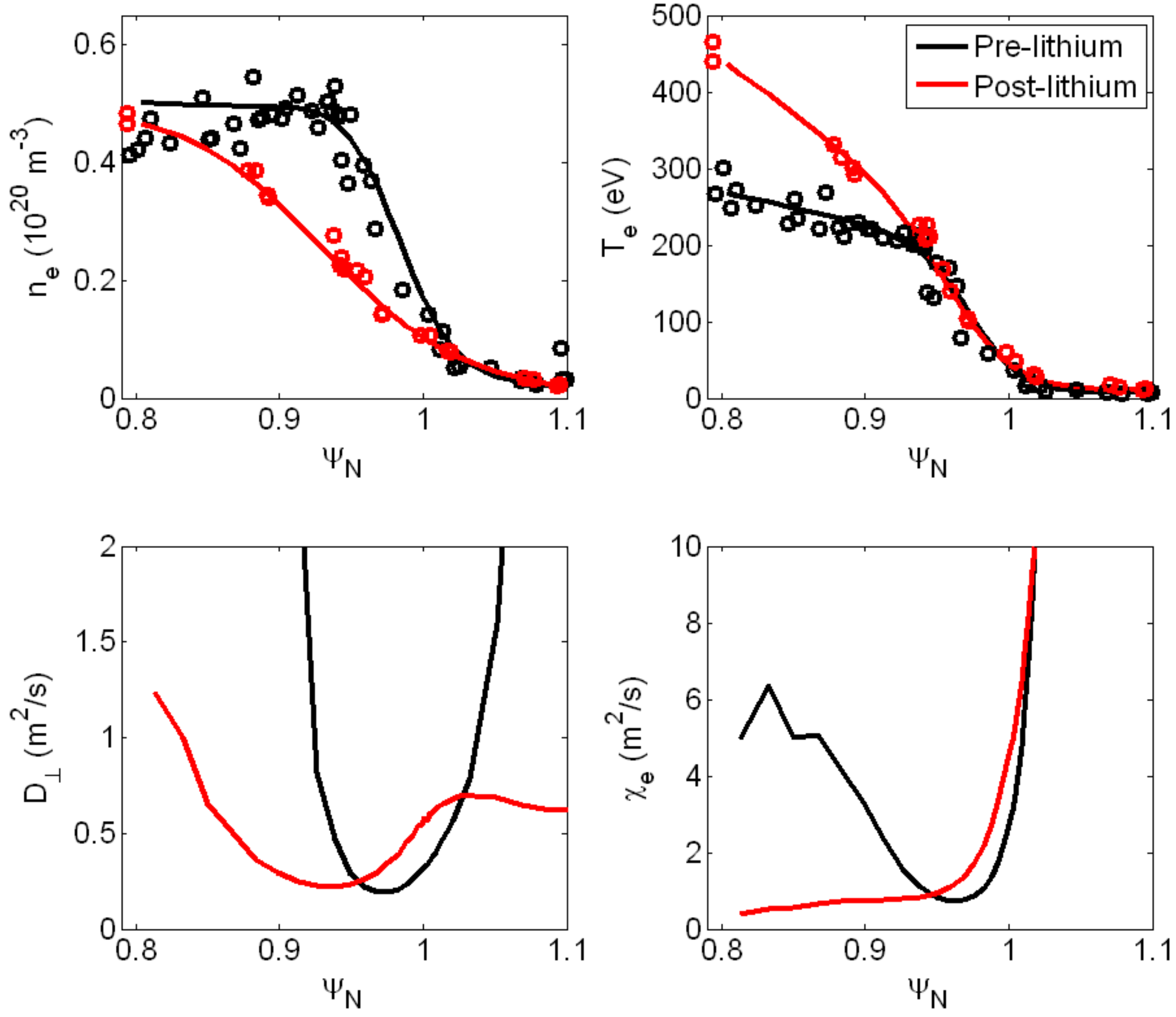


Widening of transport barrier persists when C is included in modeling

- Profiles are refit including carbon

- Qualitatively similar to deuterium-only results
  - Transport similar near separatrix
  - Barrier region in $D_\perp$, χ_e is wider with lithium

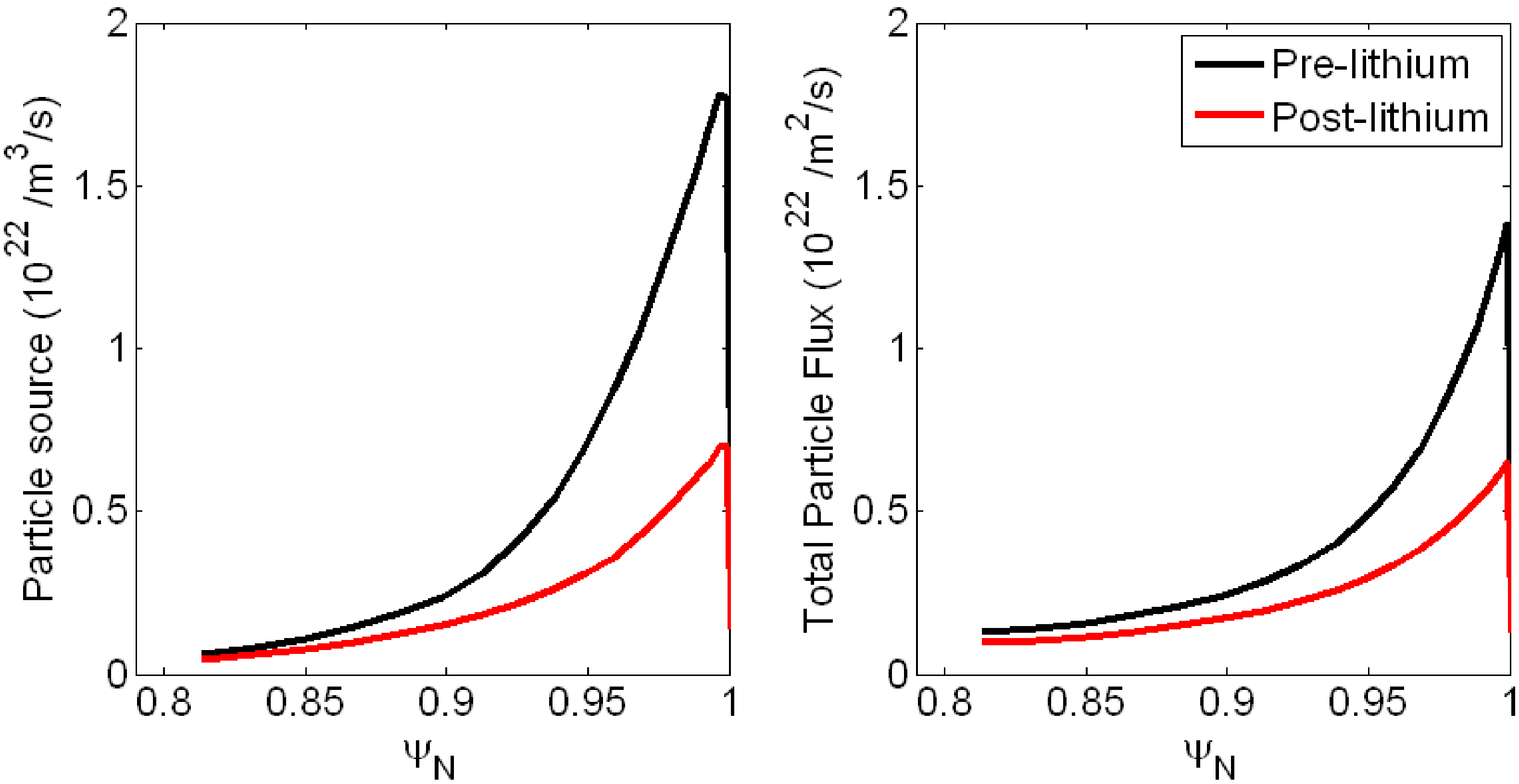
- $D_\perp$ increases somewhat to counteract pinch
  - Now $D_\perp$ increases in side ψ_N~0.9 with lithium
  - Better to consider an “effective” diffusivity



Summary

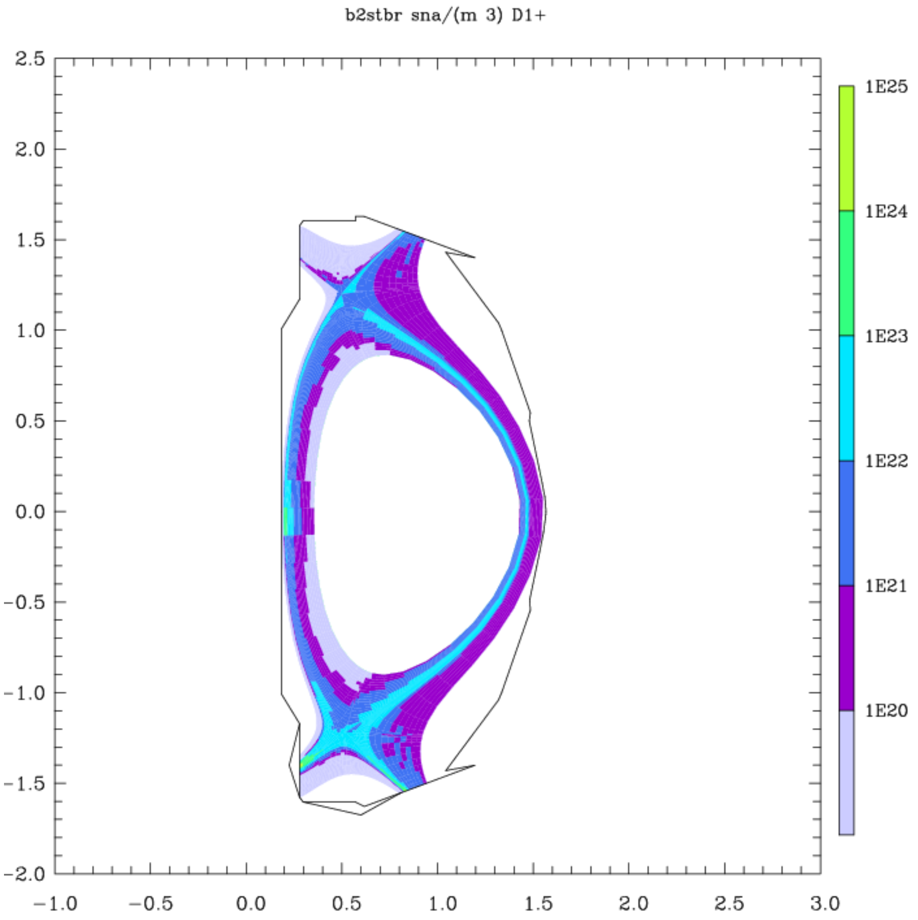
- Measured pedestal profile changes with lithium are reproduced in 2-D edge modeling
- Matching D_α measurements indicates R is reduced from 0.98 to 0.9 with lithium coatings
- Matching midplane profiles requires change to transport coefficients in addition to recycling
  - Lower R is not enough
  - Transport barrier widens with lithium, giving wider pedestal

Particle source, flux is reduced by factor of ~2 with lithium



2D Particle Source Rates

Pre-lithium



Post-lithium