NSTX

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The steps by which lithium wall coatings lead to ELM elimination in NSTX

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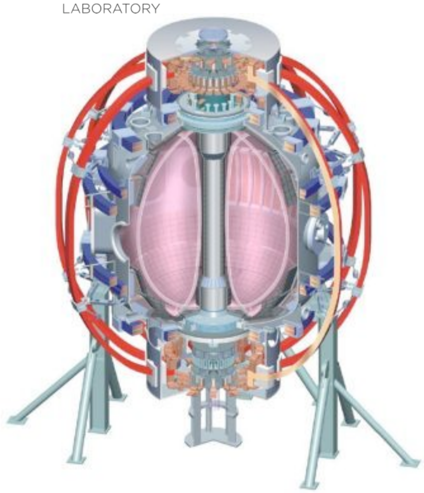

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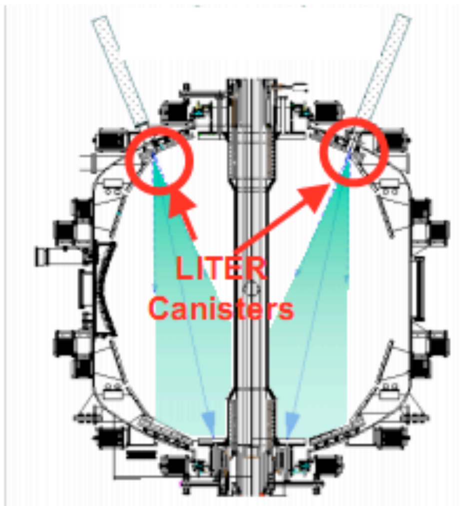
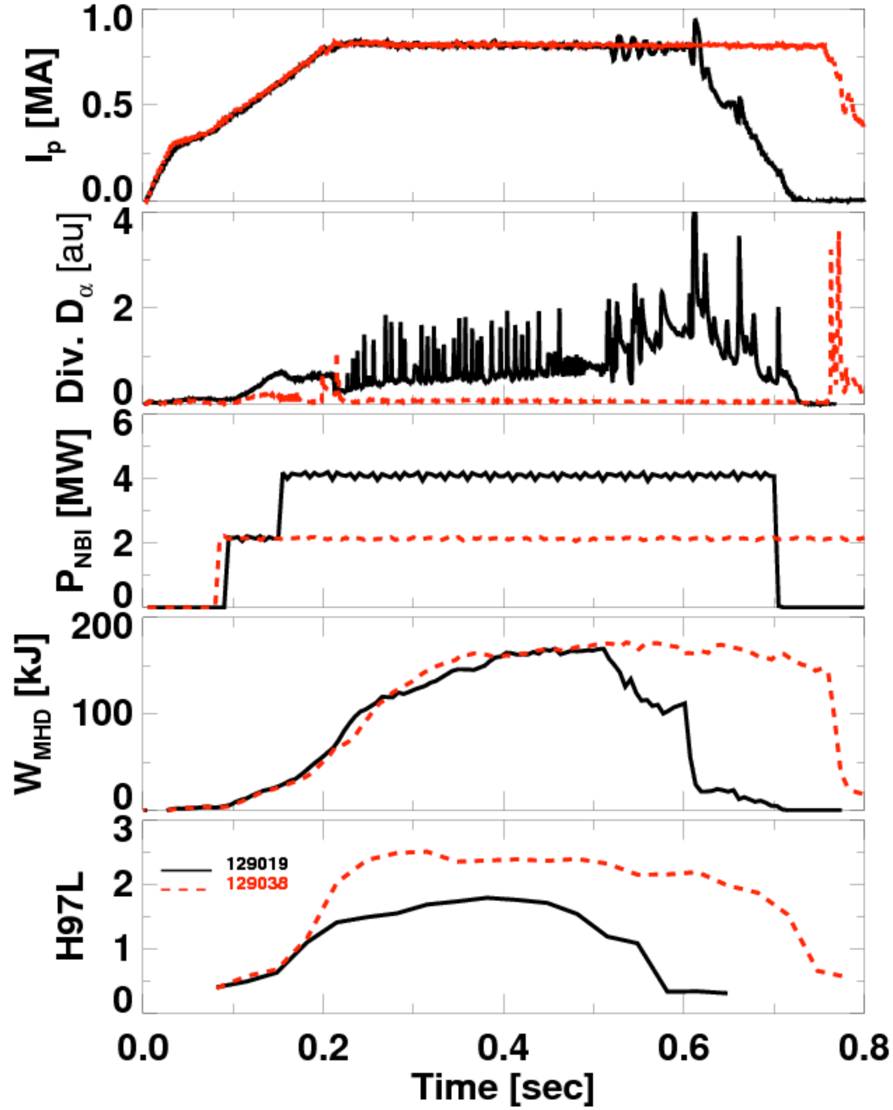
Type I ELMs eliminated, energy confinement improved with lithium wall coatings; (P_{rad} increases as in ELM-free H-mode)



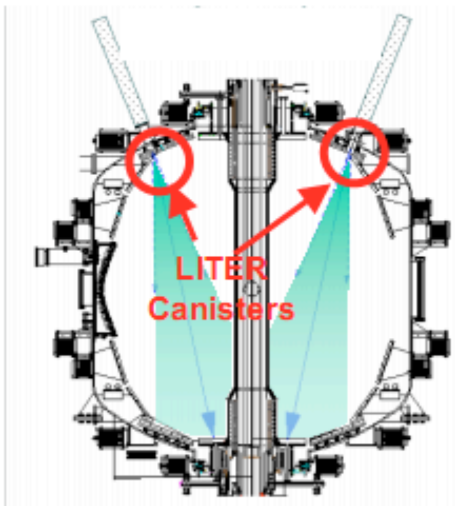
~ 700mg Li between 129037 and 129038

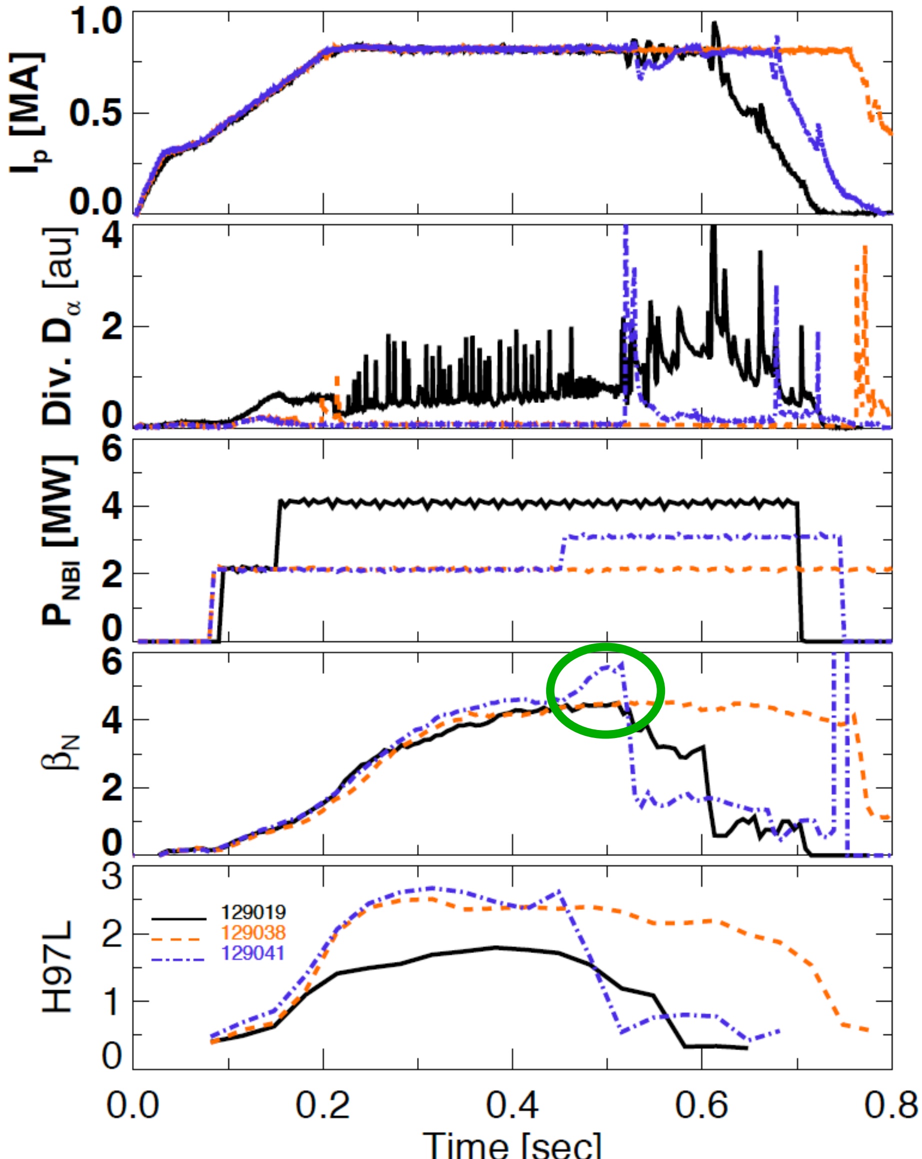


- Without Li, With Li *(pre-LLD)*
- ELM-free, reduced divertor recycling
- Lower NBI to avoid β limit
- Similar stored energy
- H-factor 40%↑

H. Kugel, PoP 2008
R. Kaita, IAEA 2008
M. Bell, PPCF 2009
D. Mansfield, JNM 2009
R. Maingi, PRL 2009

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

Pedestal gradients increase from ψ_N=0.8-0.94; still stable to ELMs

ψ_N from 0.95-1

Li coatings reduce recycling and core fueling
→
n_e near separatrix reduced
T_e near separatrix unchanged
→
n_e, P_e gradient reduced
P_i gradient unchanged
→
J_{bs}, $J_{||}$ reduced - stabilizing

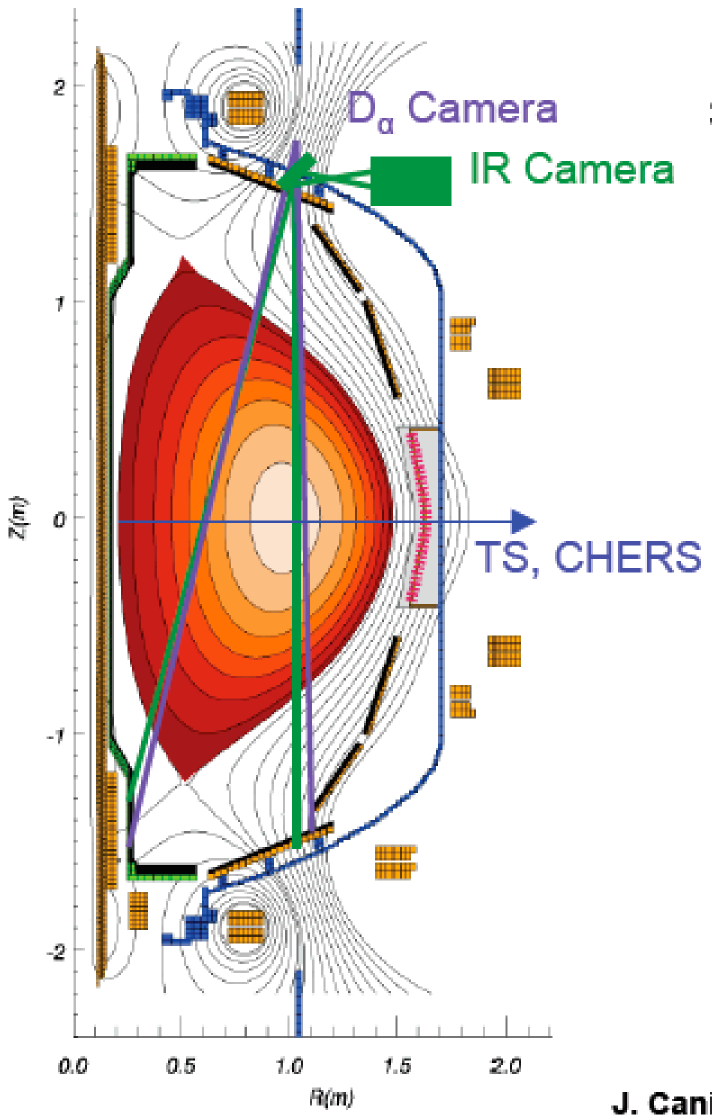
Data, SOLPS | Data | Data | Kinetic EFITs, ELITE

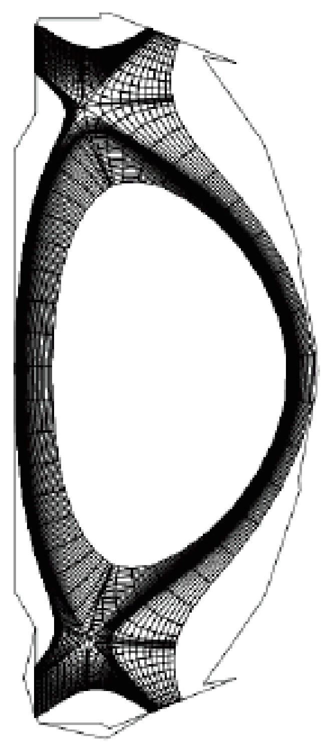
ψ_N from 0.8-0.94

Edge χ_e, D reduced from ψ_N = 0.8-0.94
→
n_e profile width increased; T_e profile modified for ψ_N < 0.95
→
Edge P_e profile follows n_e; peak P' shifts farther from separatrix
→
J_{bs}, $J_{||}$ increased but far from separatrix; improves stability to kink/peeling modes

SOLPS | Data | Data | Kinetic EFITs, ELITE

Divertor recycling and far edge cross-field transport quantified with data-constrained SOLPS modeling



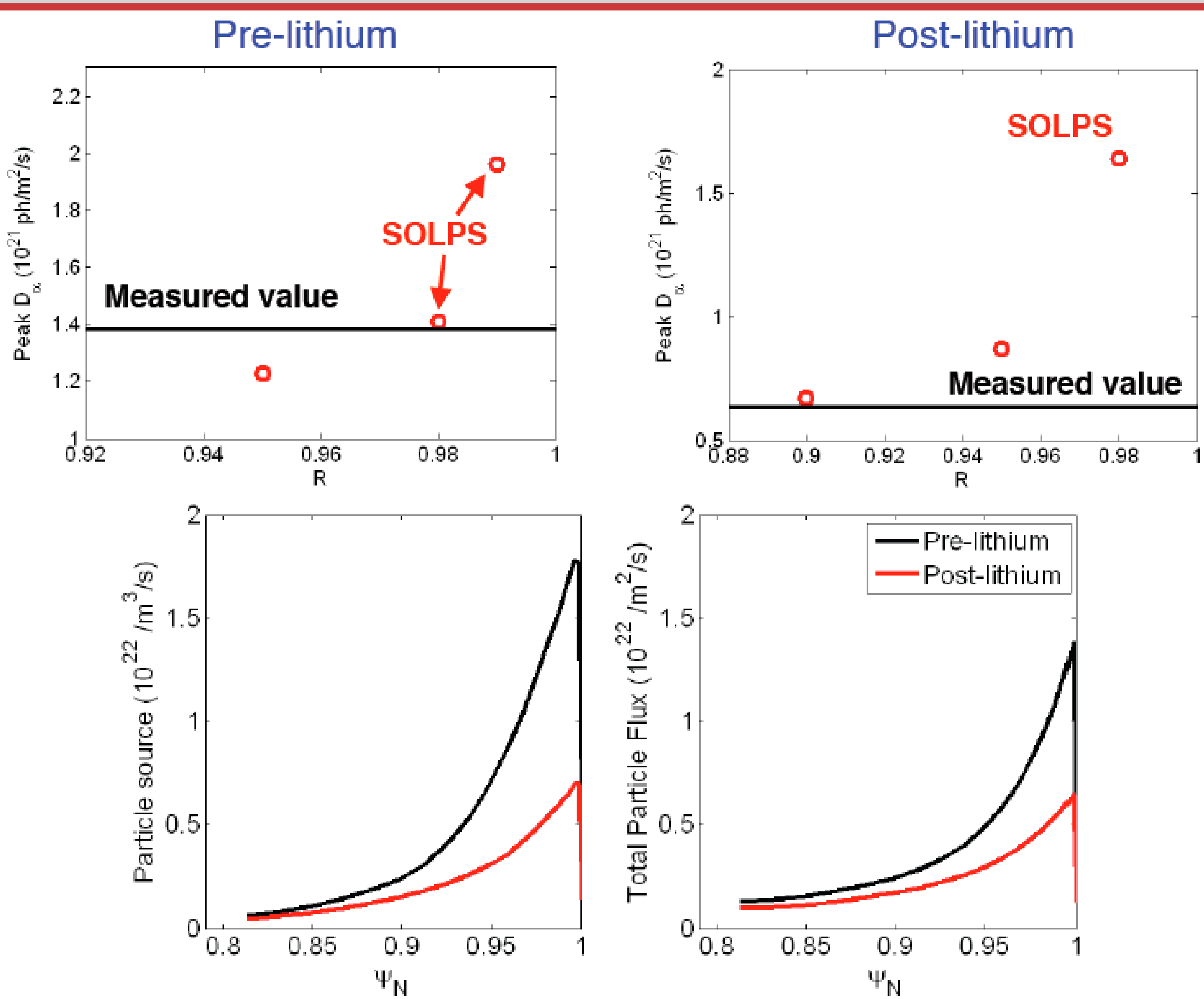


J. Canik PoP 2011

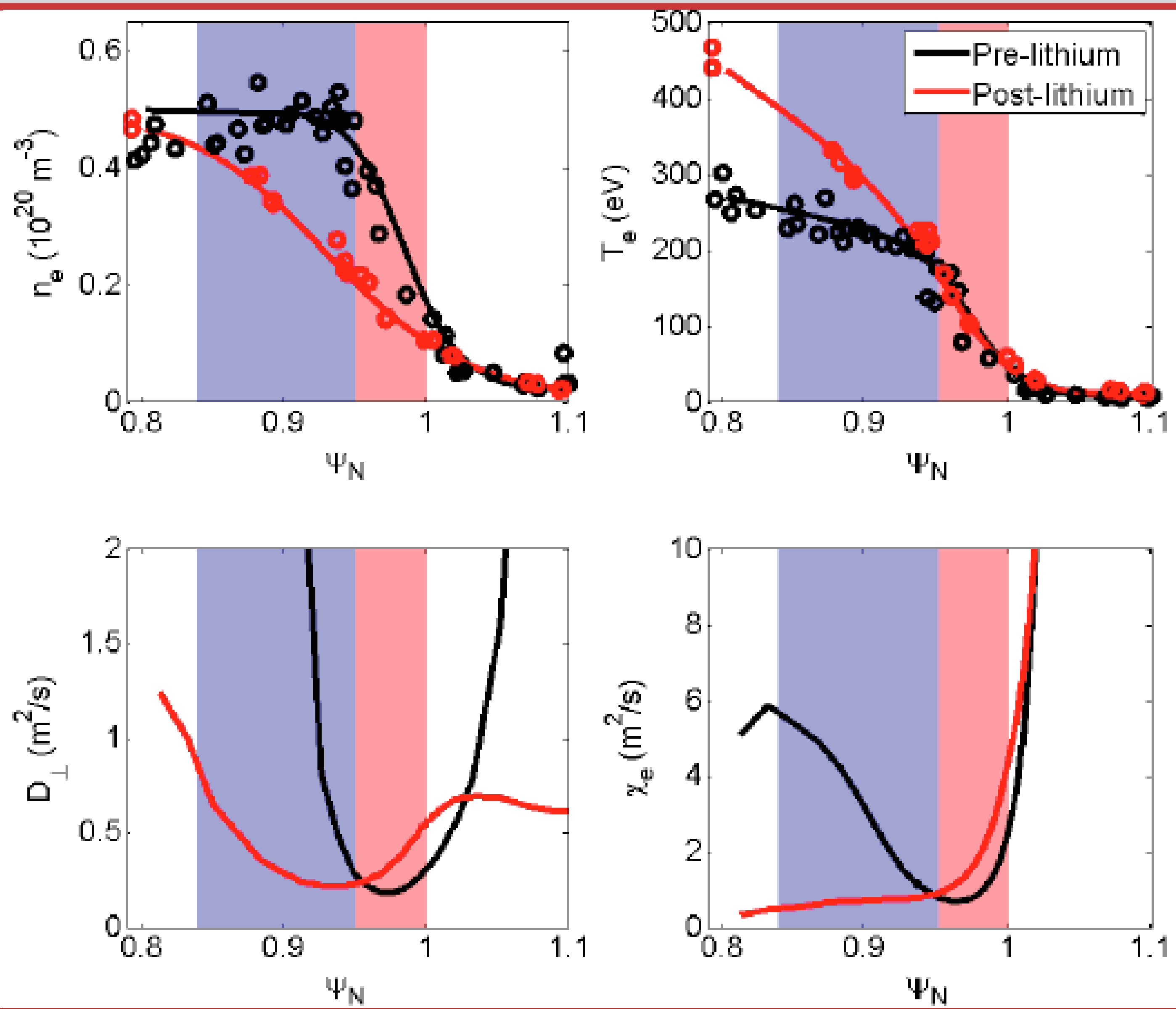
- SOLPS (B2-EIRENE: 2D fluid plasma + MC neutrals) used to model NSTX experimental data
  - Iterative Method
  - ✓ Neutrals, impurities contributions
  - ✓ Recycling changes due to lithium

Parameters adjusted to fit data	Measurements used to constrain code
Radial transport coefficients $D_\perp$, χ_e, χ_i	Midplane n_e, T_e, T_i profiles
Divertor recycling coefficient	Calibrated D_α camera
Separatrix position/T_e^{sep}	Peak divertor heat flux

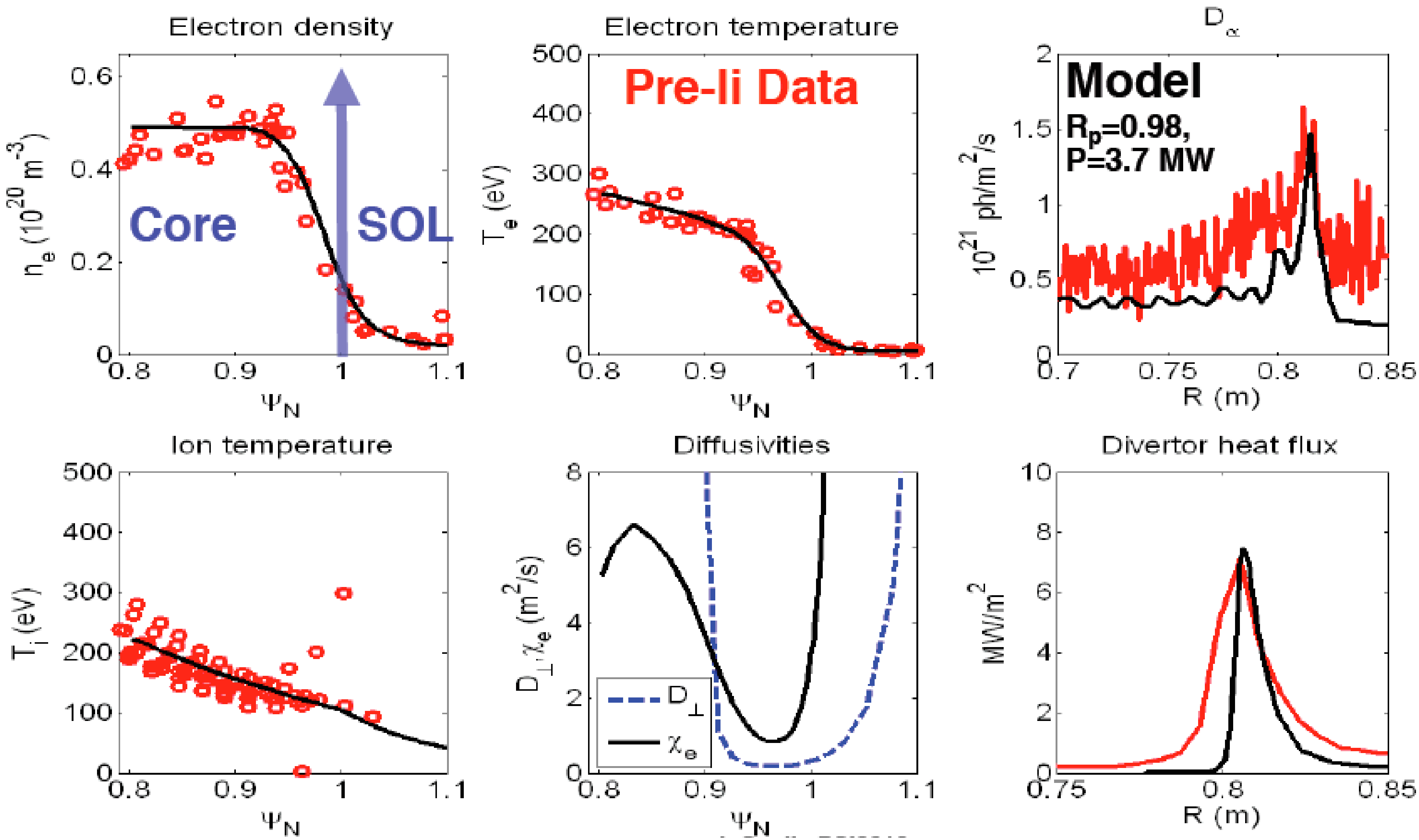
Lithium reduces recycling (D_α data) and core fueling (SOLPS interpretive analysis)



Profile changes from ψ_N to 0.95-1.0 indicates increased D, χ_E
Profile from ψ_N to 0.8-0.94 indicates reduced D, χ_E

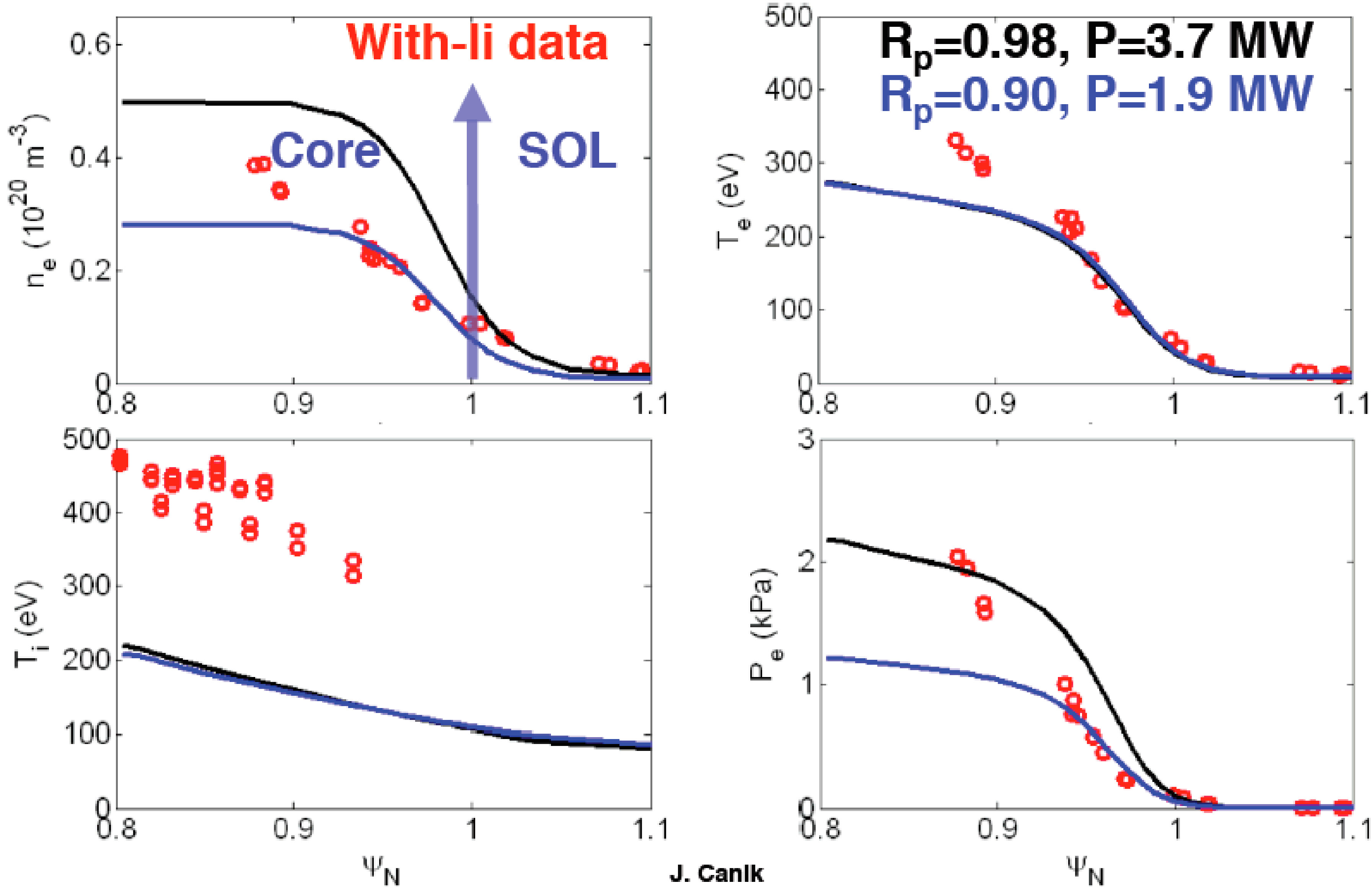


2-D modeling used to model power and particle balance of baseline ELMy discharge



Canik, JNM 2011; Canik, PoP 2012

With-lithium discharge profiles not reproduced with simple recycling coefficient change



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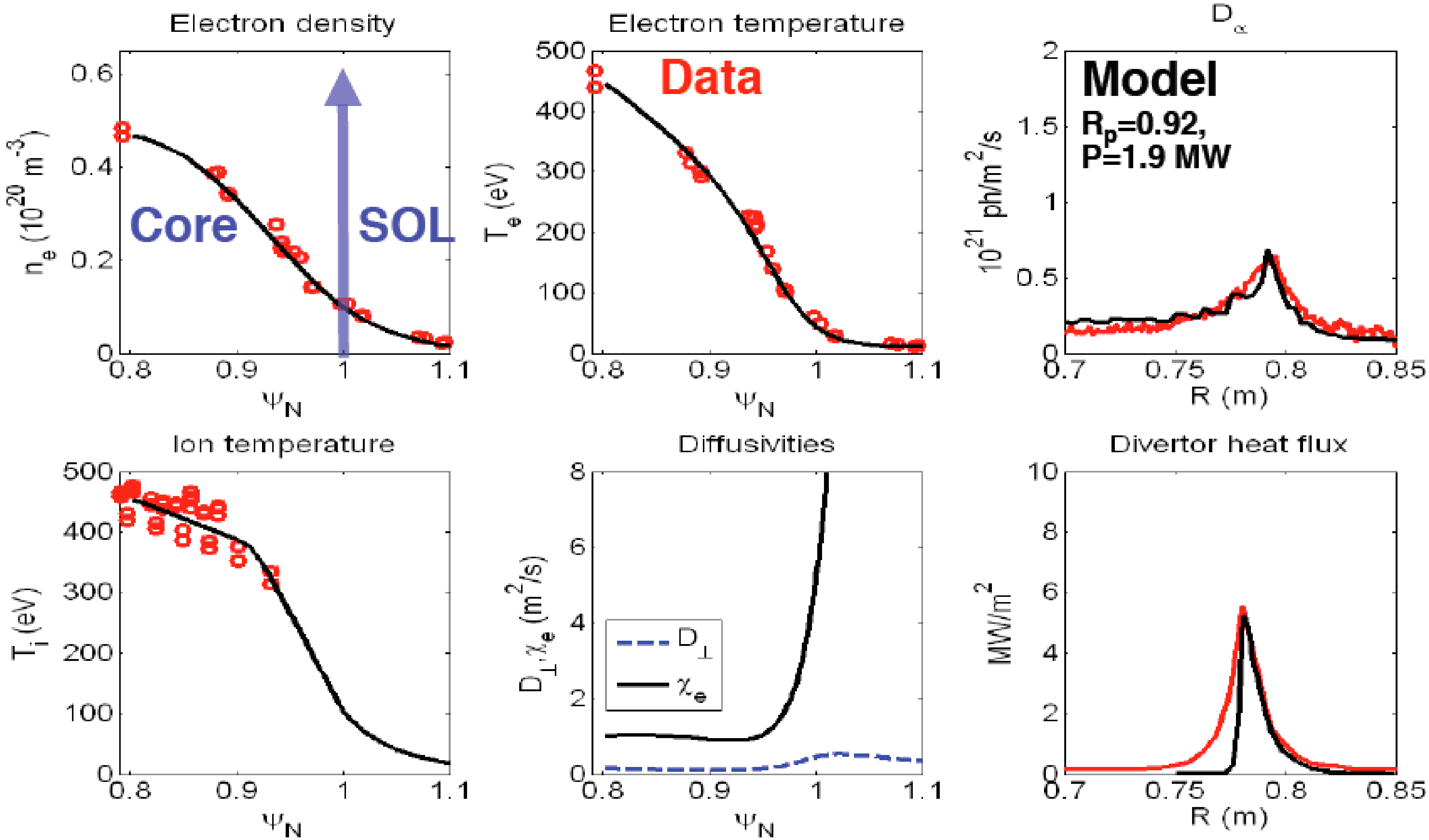
With-lithium discharge profiles better matched with transport and recycling coefficient change



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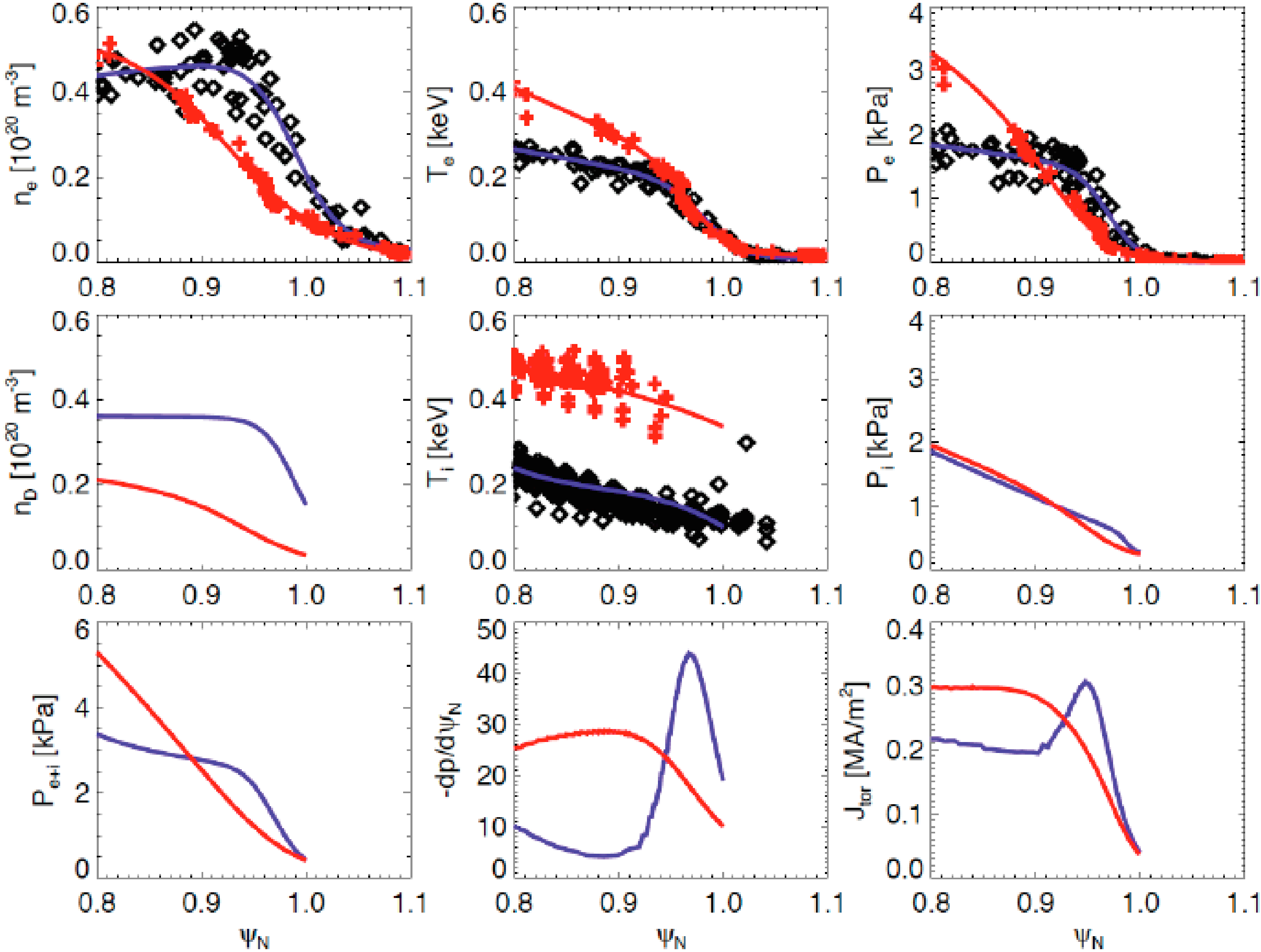
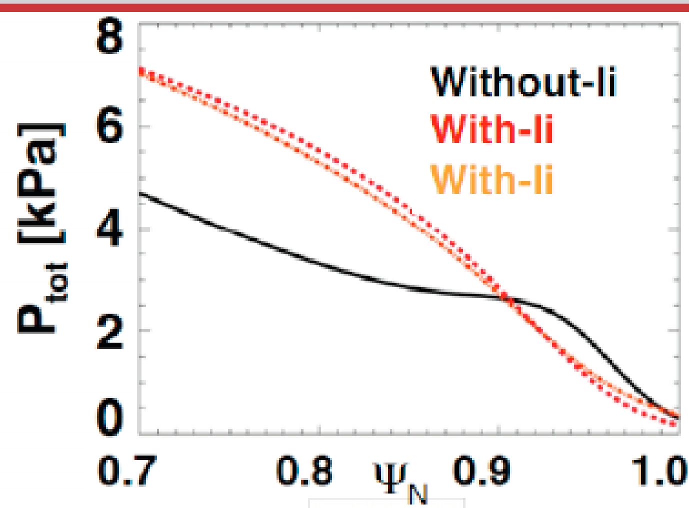
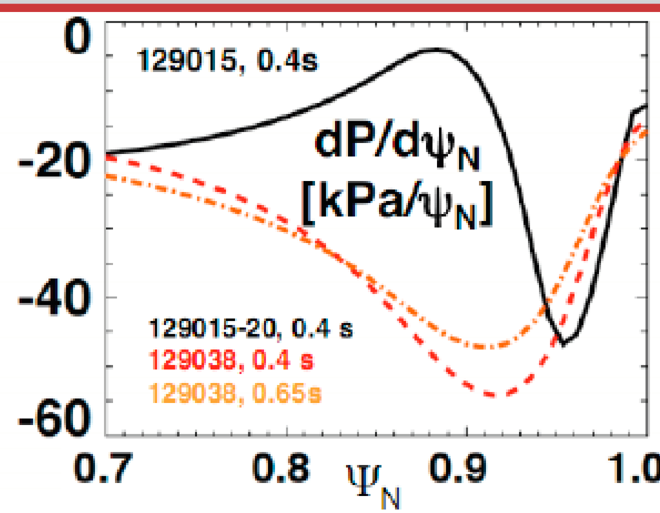
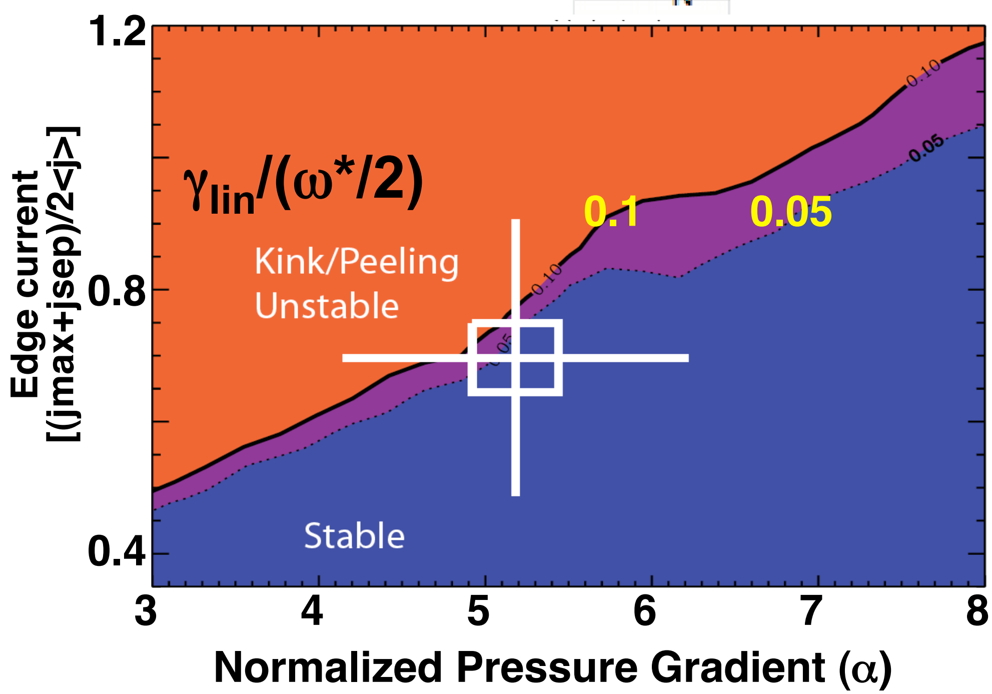
n_e (T_e) gradient near separatrix reduced (unchanged); P_e profile follows n_e; P_i unchanged -> P_{tot} follows P_e

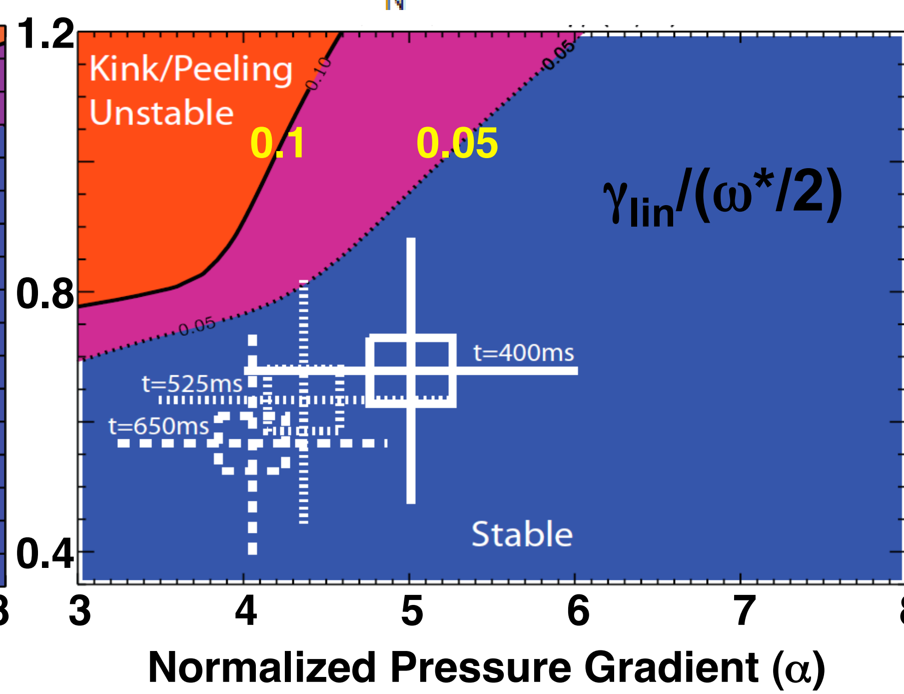


With-li profiles stable to peeling/ballooning modes, despite higher edge bootstrap current and comparable maximum P'









Summary and Conclusions

- ELM-free phases increase gradually with lithium deposition, with discharges becoming ELM-free (Boyle, adjacent poster, PPCF 2011)
  - n_e profile gradient reduced with increasing lithium
  - Edge T_e, T_i increase and profiles change substantially
- H-factor increased up to 50% for thickest lithium coatings
  - Region of low D, χ_{eff} extends inward from H-mode barrier
  - Global stability limits (β_N ~ 5.5-6) encountered before edge (ELM) stability limits
- The decrease in pressure and boostrap current near separtrix ($0.95<\psi_N<1$) stabilizing
- The increase in pressure and boostrap current drop from $0.80<\psi_N<0.94$) stabilizing for current driven modes, and modestly destabilizing to pressure driven modes (but there's enough margin to stability limit due to low R/a)
  - Density profile modification crucial step toward ELM suppression

Present research areas

- What is reason for clamped T_e gradients from $0.95<\psi_N<1$?
  - Note: if profile changes were isobaric instead of isothermal, ELMs may not have been eliminated
  - ETG modes: n_e profile gradient reduced -> η_e increases -> should be stabilizing to ETG mode

- What are possible reasons for reduced D, χ_E from $0.8<\psi_N<1$?
  - Reduced neutral density from reduced recycling -> reduced CX momentum drag -> higher edge toroidal rotation -> higher rotation gradient -> higher E X B shear -> stabilizing (Cao, PPCF 2011 subm)
  - Increased n_e profile gradient stabilizing to both μtearing (Guttenfelder PRL 2011) and ETG (Ren PRL 2011)
  - Reduced particle source -> reduced turbulence drive to buck out the source term (Umansky, PC; need BOUT++ calculations)

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