NSTX

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Modification of Edge Profiles, Edge Transport, and ELM Stability with Lithium in NSTX

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Rajesh Maingi, OAK RIDGE National Laboratory

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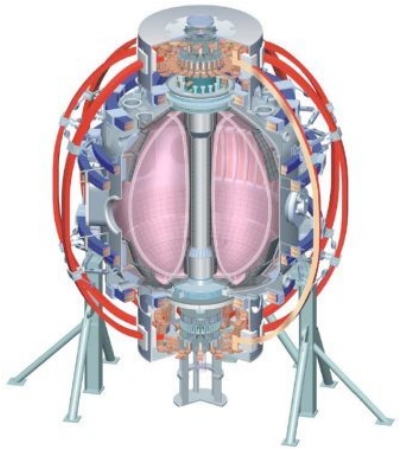
and the NSTX Research Team

23rd IAEA FEC Conference
Daejeon, Rep. of Korea
11-16 Oct 2010

PPPL PRINCETON PLASMA PHYSICS LABORATORY

GENERAL ATOMICS



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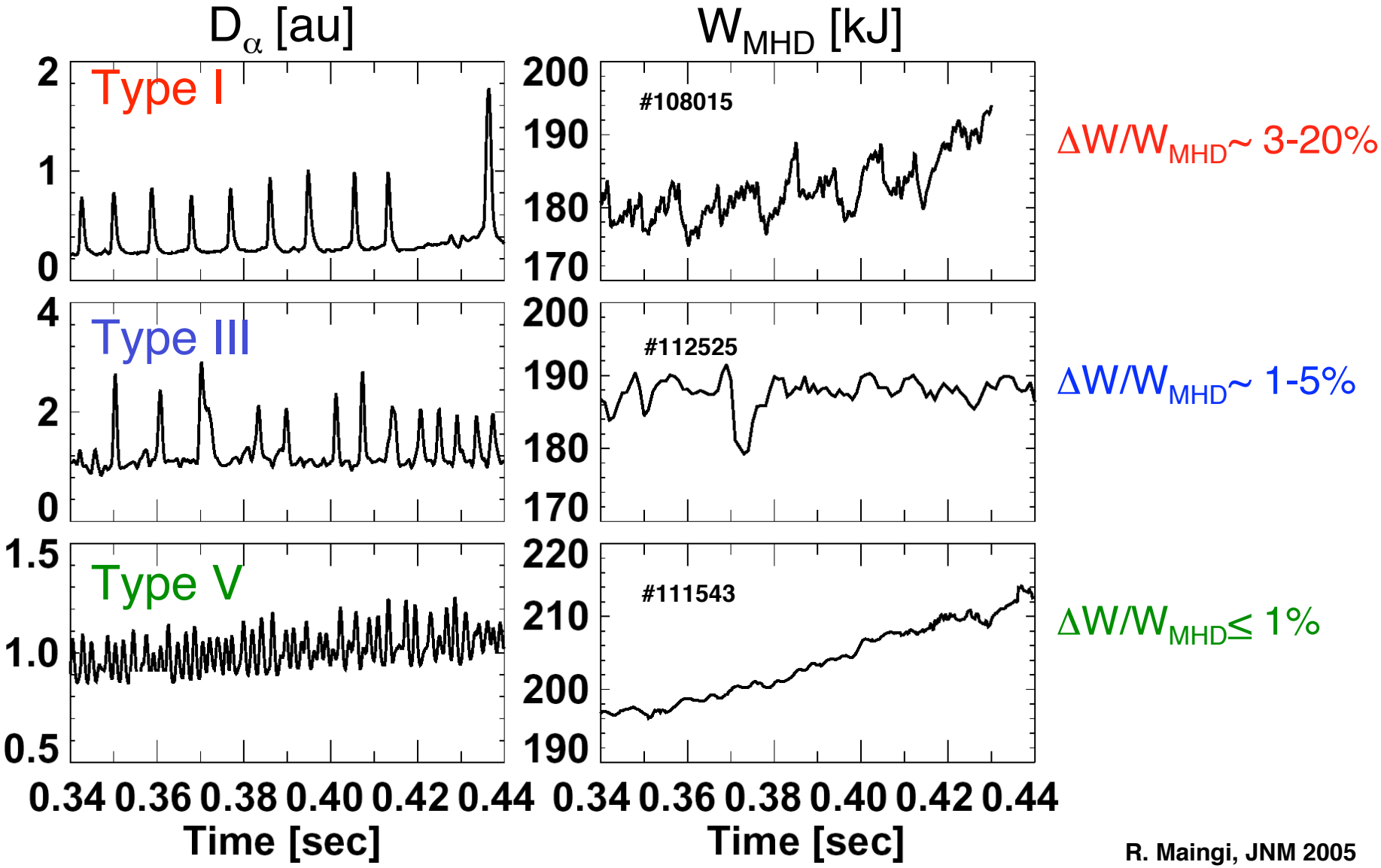
Lithium wall coatings control recycling and edge density, and lead to ELM suppression

- End points of a well-controlled lithium coating sequence in which ELMs gradually disappear
  - Edge density, temperature, rotation and pressure profiles are modified with lithium
  - Edge cross-field D and χ_e drop from $\psi_N \sim 0.8$-0.95
- Edge peak pressure gradient moves farther from separatrix, and pedestal gets wider
  - Calculated bootstrap current changed, and edge stability improved

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



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

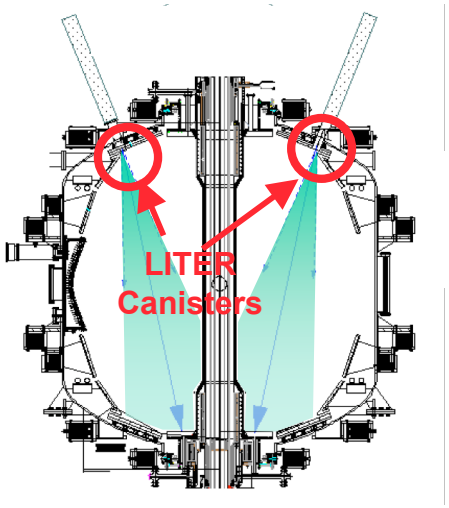
$\Delta W/W_{MHD}$~ 1-5%

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

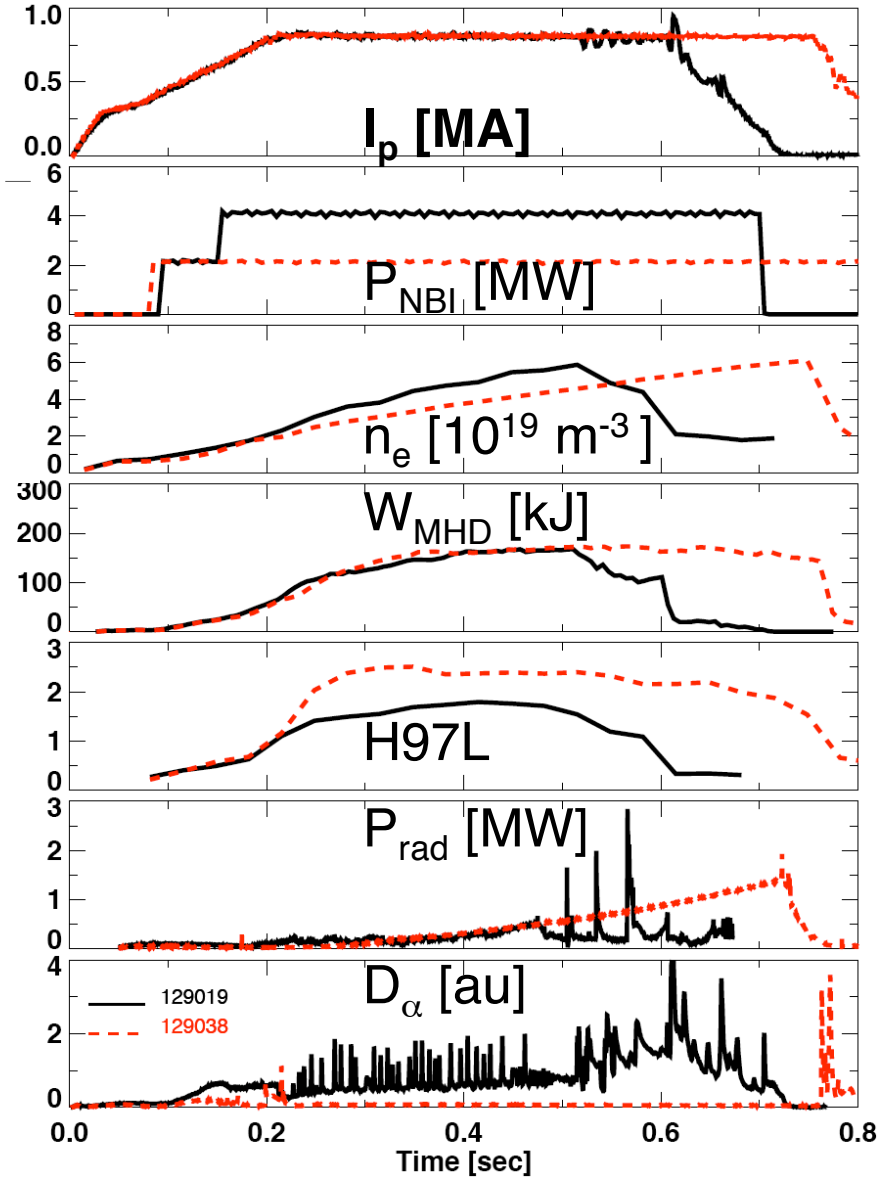
R. Maingi, JNM 2005

Type I ELMs eliminated by lithium wall coatings

Predicted* by
L. Zakharov
in 2005



~ 700mg Li
before 129038

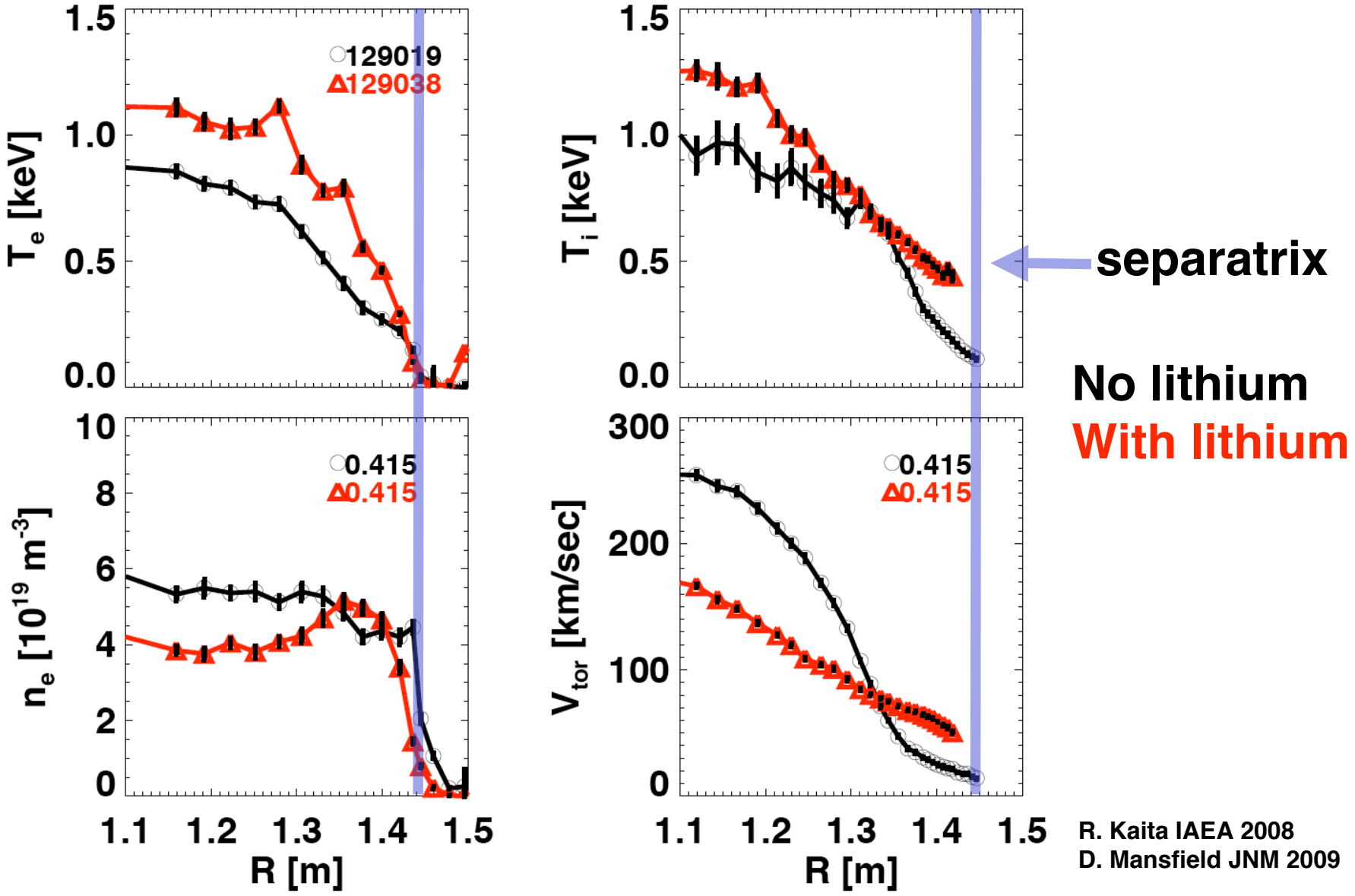


- Without-Li, With Li
- Lower NBI to avoid β limit
- Lower n_e
- Similar stored energy
- H-factor 40%↑
- Higher P_{rad} /P_{heat}
- ELM-free, reduced divertor recycling

H. Kugel PoP 2008
R. Maingi PRL 2009
M. Bell PPCF 2009

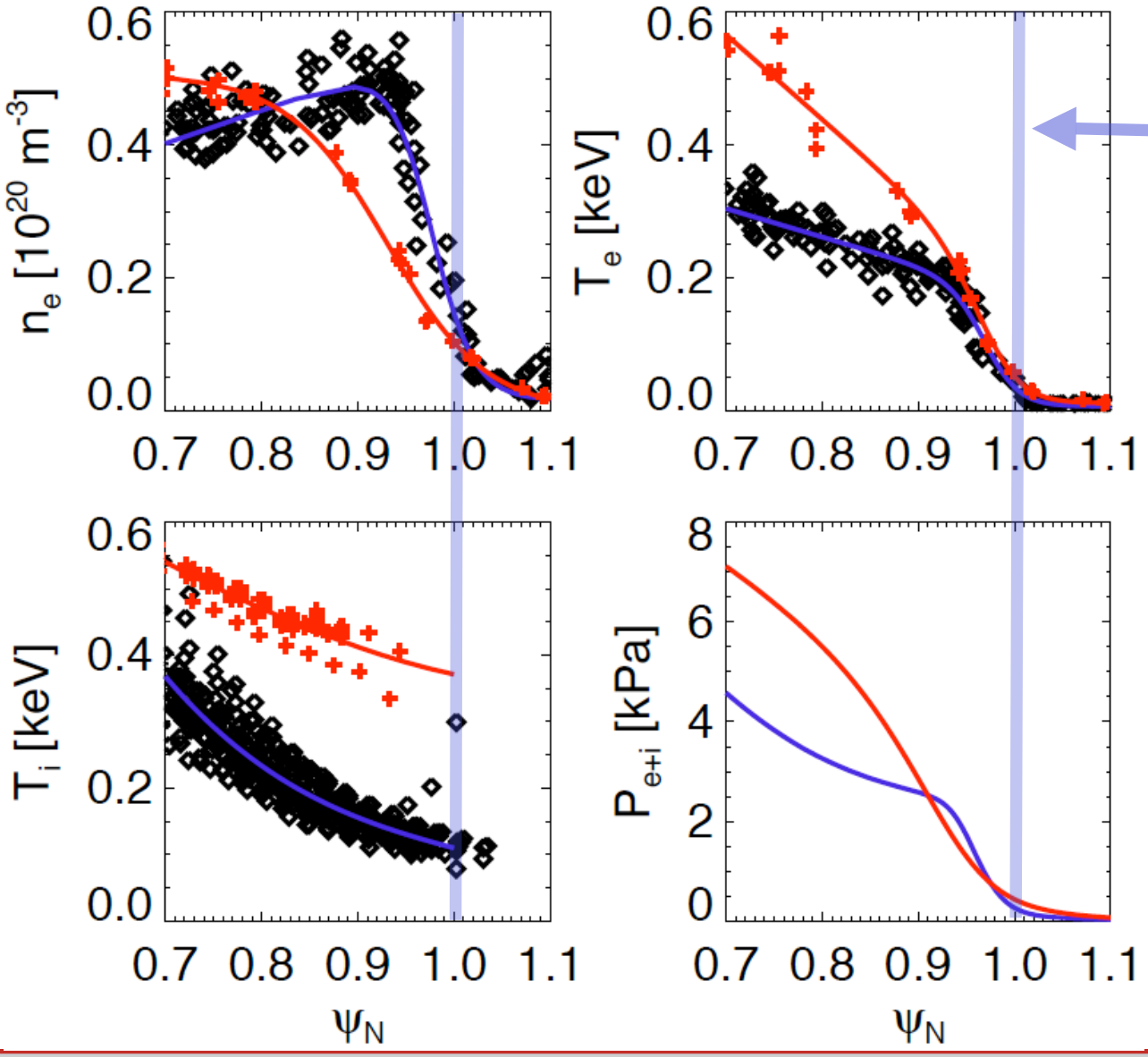
*** L. Zakharov, JNM 2007**

T_e, T_i increased and edge n_e decreased with lithium coatings



R. Kaita IAEA 2008
D. Mansfield JNM 2009

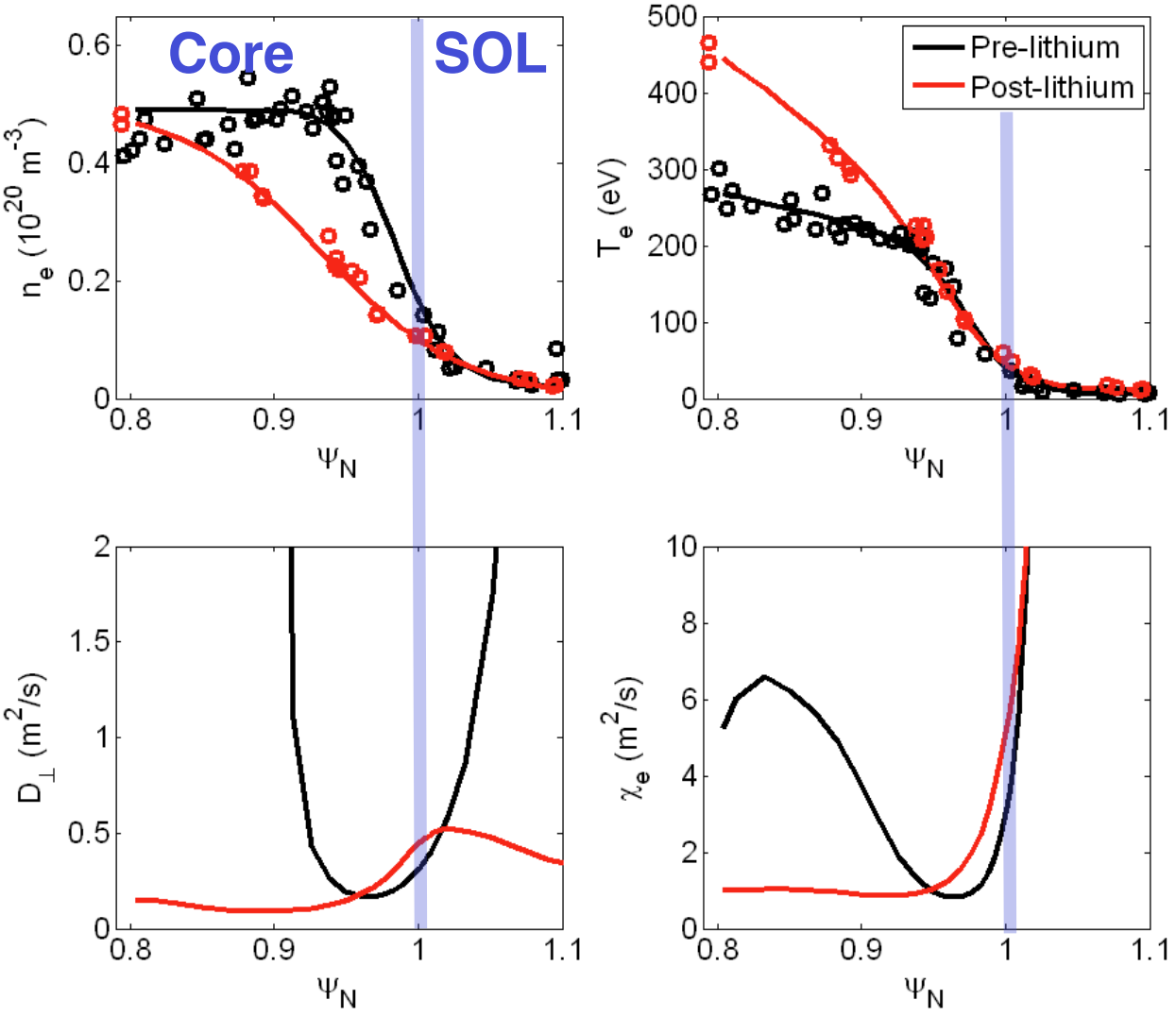
Edge pressure profile modified with lithium



No lithium
With lithium

(multiple time slices)

Profiles in discharges with lithium coatings only reproduced with recycling *and* transport reduction



R_p=0.98, P_{loss}=3.7 MW

R_p=0.92, P_{loss}=1.9 MW

(2D Plasma Neutral Transport Modeling With SOLPS)

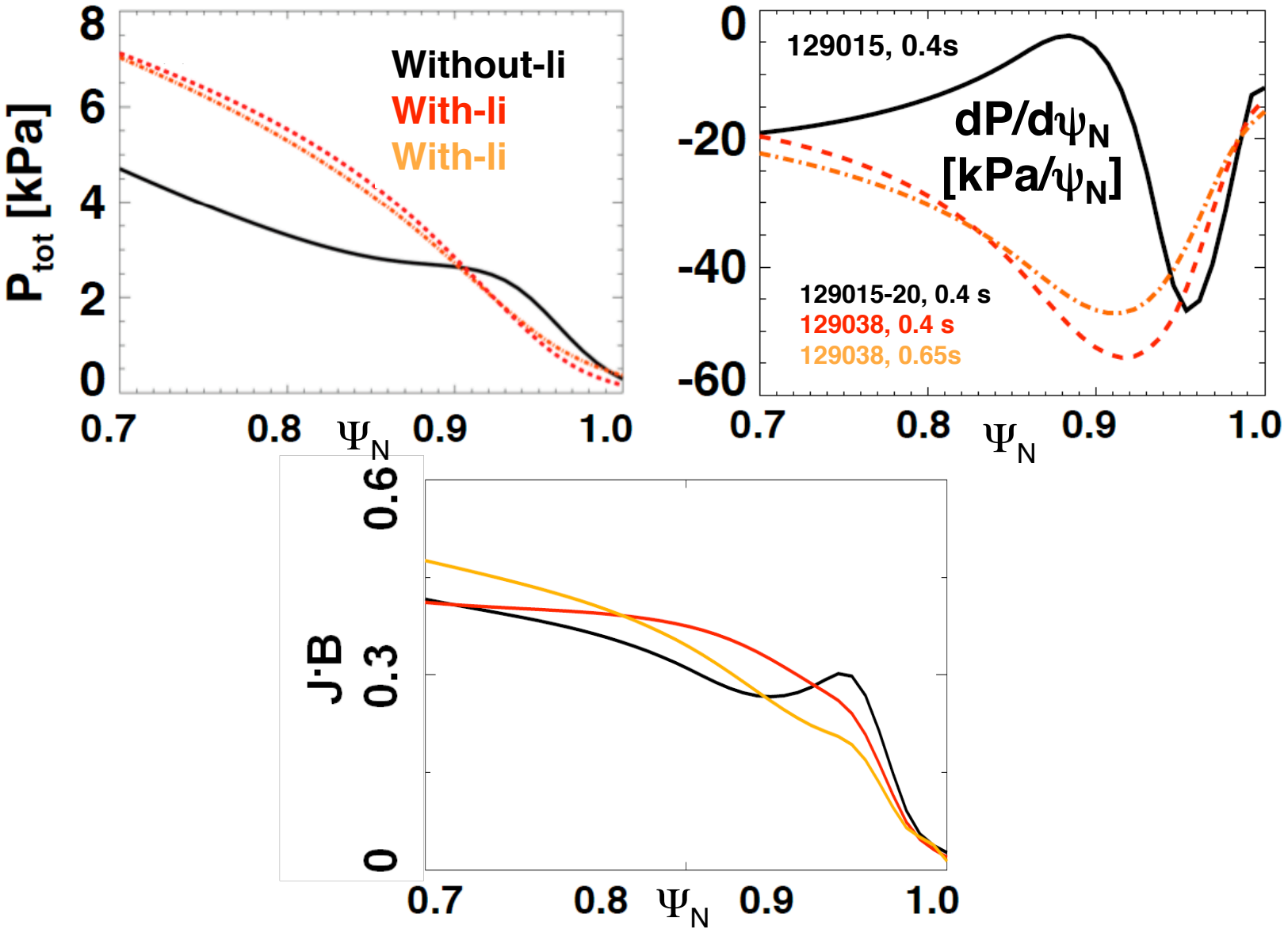
R_P=divertor recycling coefficient

J. Canik, PSI 2010

Kinetic equilibrium fits using multiple data time slices integral to analysis procedure

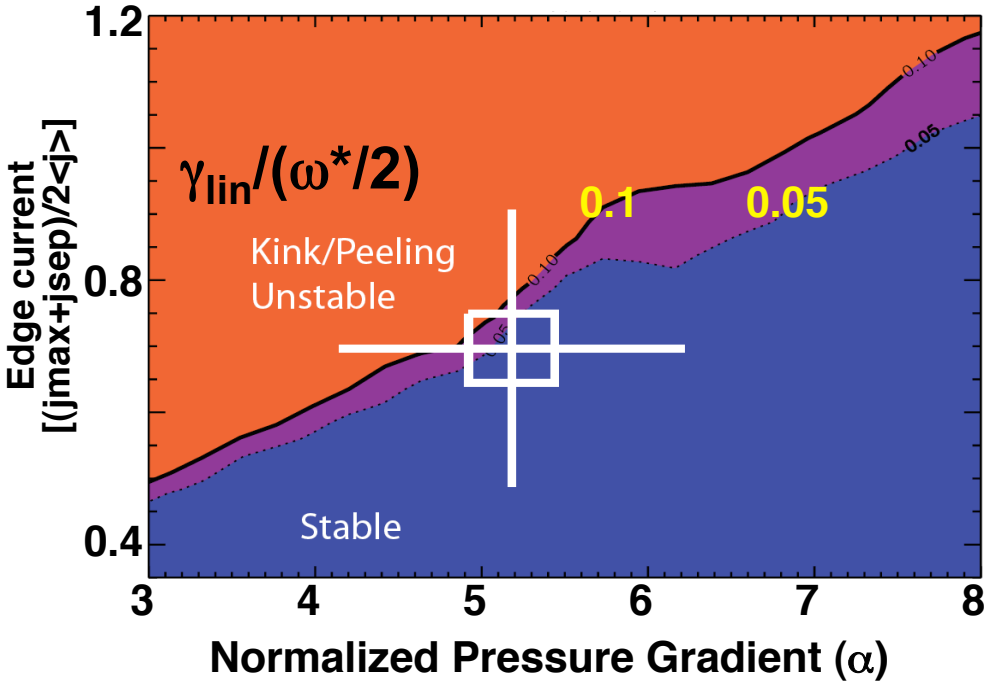
- Profile fitting of multiple time slices (mapped to ψ_N) with standard procedures used as target for kinetic EFITs
  - Pre-lithium discharge profiles from last 20% of ELM cycle
  - Post-lithium discharge profiles used in 100-200 msec windows
- Free boundary kinetic EFITs run to match kinetic pressure profiles
  - Edge bootstrap current computed from Sauter neoclassical model
    - No direct measurement ➡ biggest uncertainty
  - Stability evaluated with PEST code
- Fixed boundary kinetic EFITs run with variations of edge pressure gradient and edge current
  - Stability boundary evaluated with ELITE code

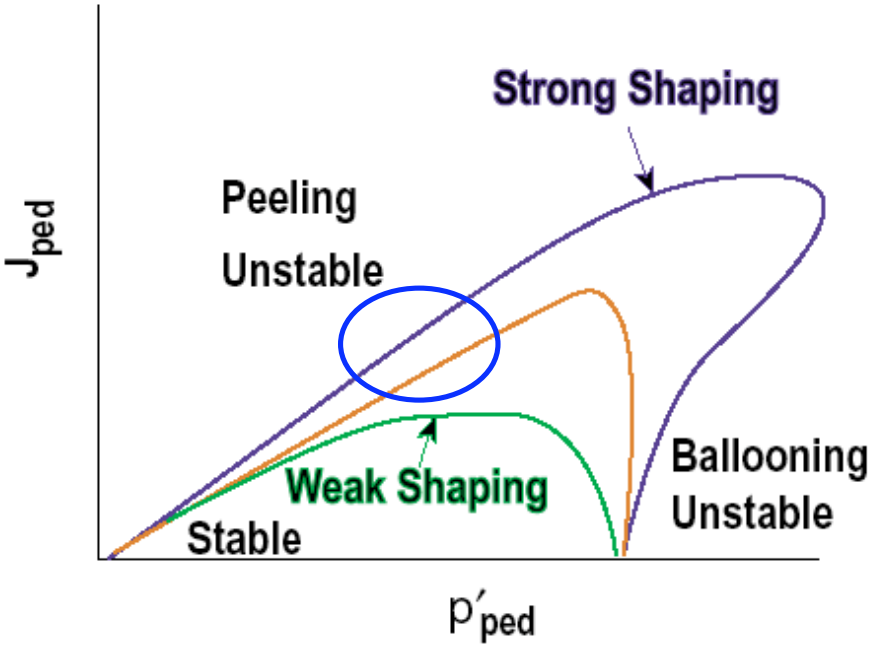
Peak edge pressure gradient and bootstrap current farther from separatrix with lithium coatings



Pre-lithium edge profiles close to kink/peeling instability threshold (ELITE)

No lithium

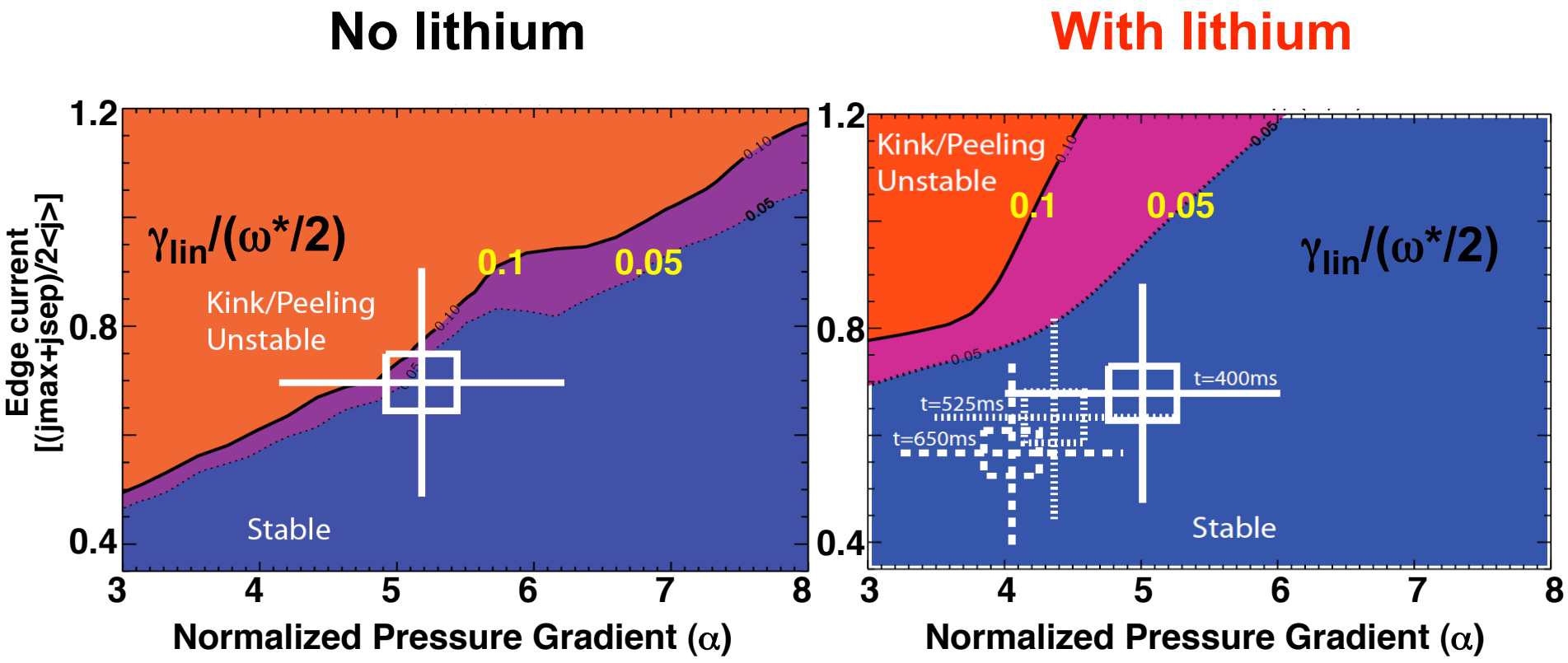




- Low n=1-5 pre-cursor oscillations observed before ELM crash
- Mode growth rates low - why not diamagnetically stabilized?

R. Maingi, PRL 2009

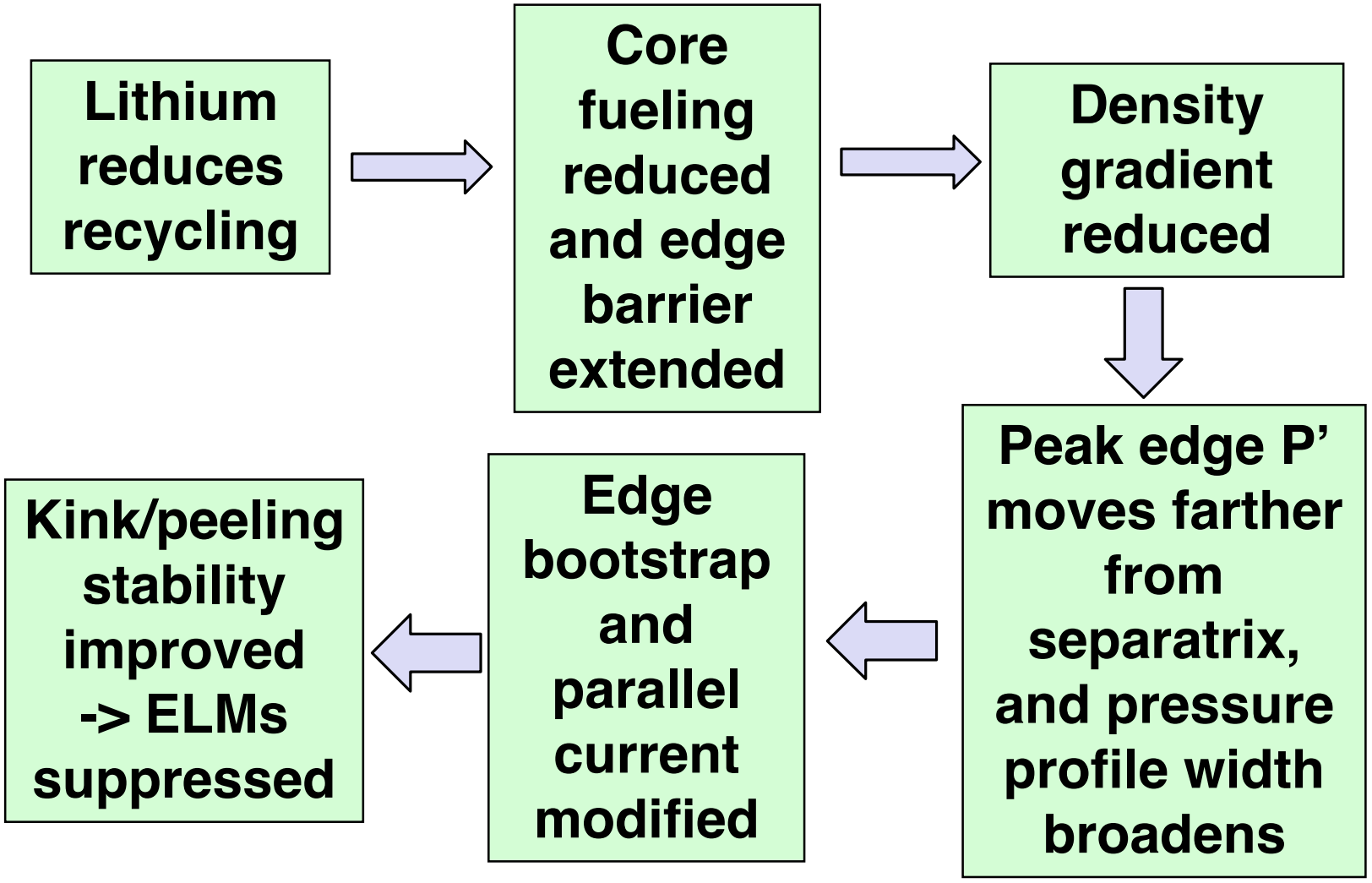
Edge profiles with lithium farther from instability threshold (ELITE)



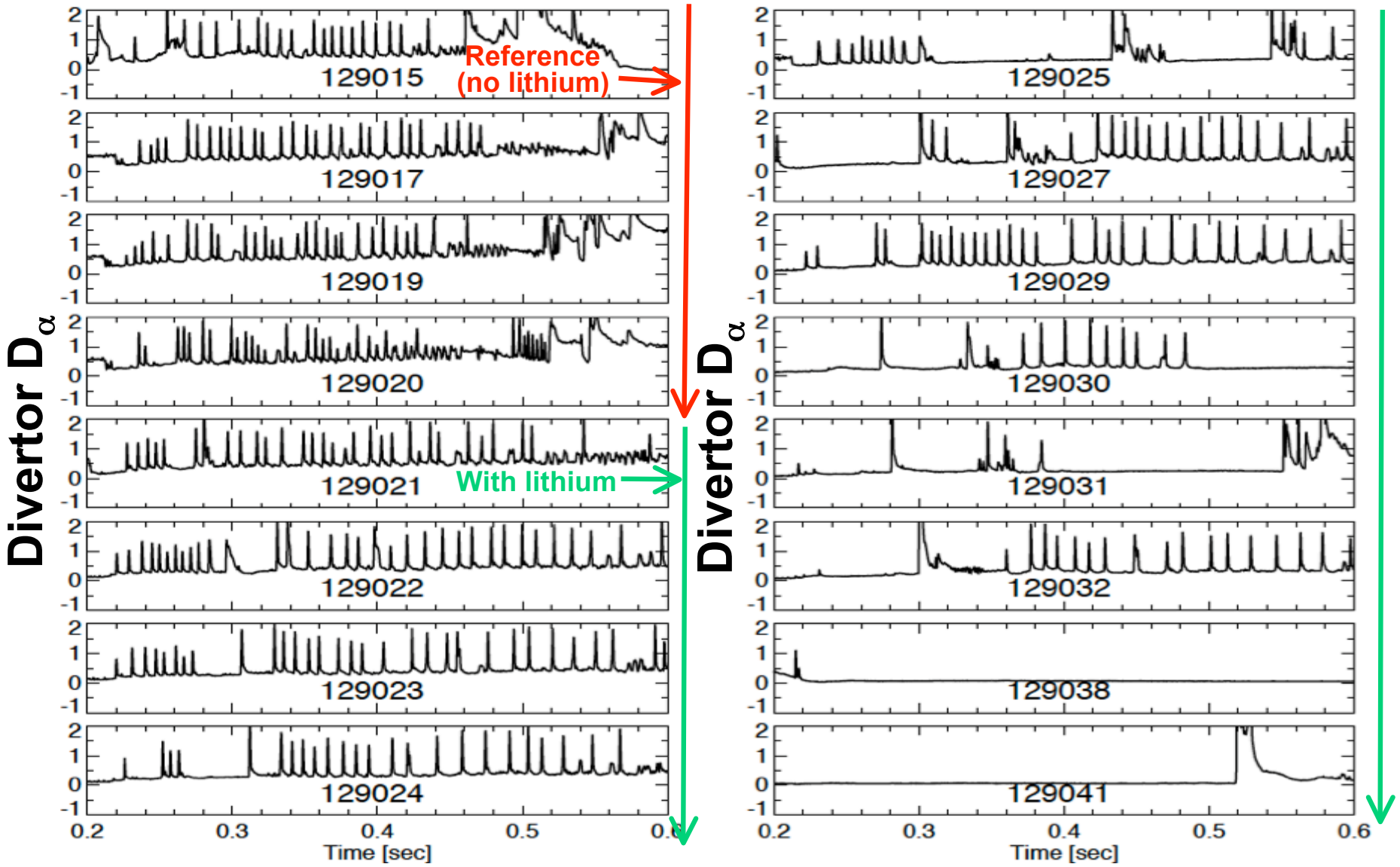
- Relative roles of wider pedestals, current farther from separatrix, and magnetic shear being assessed

R. Maingi, PRL 2009

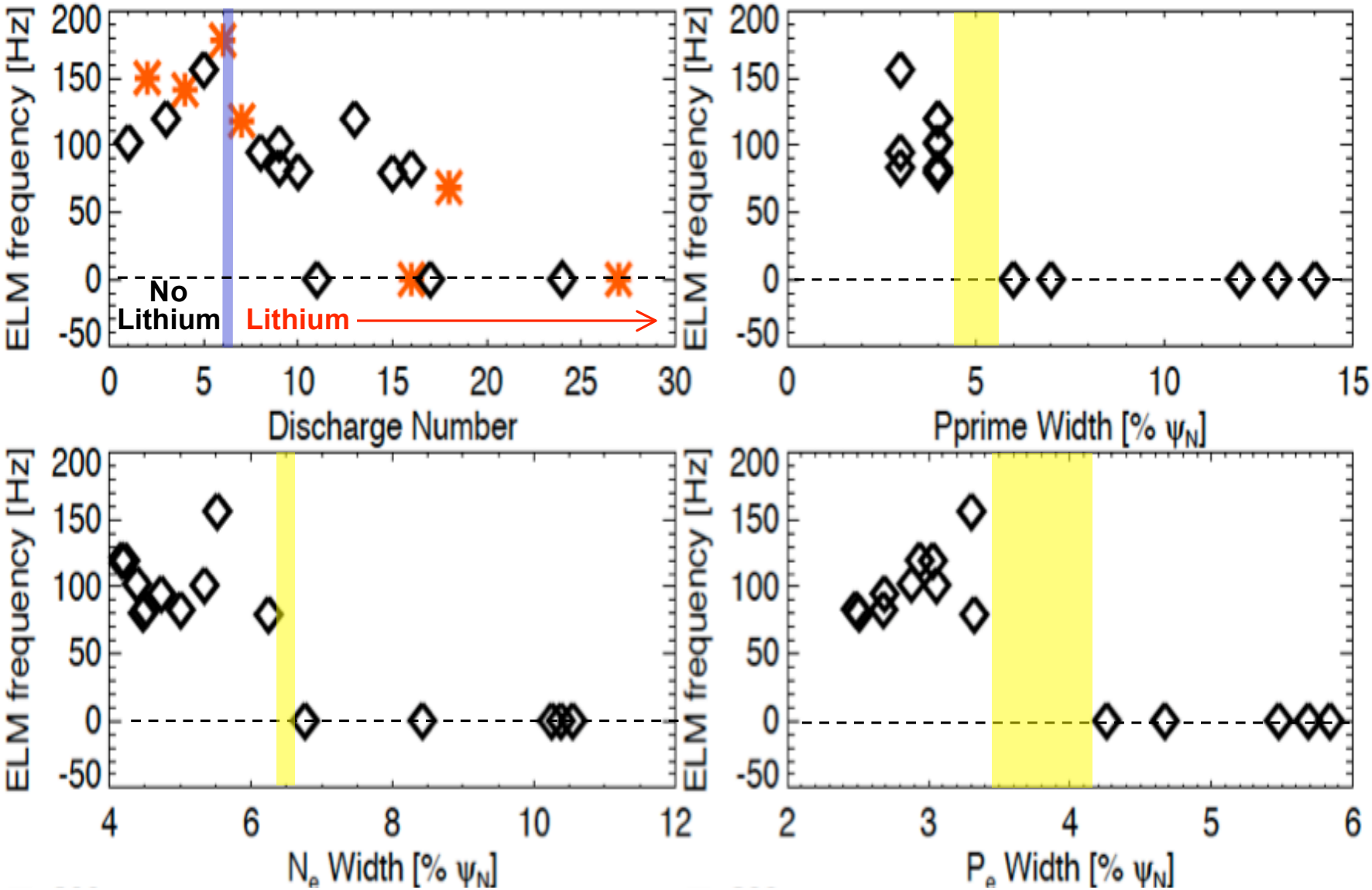
Density profile modification to lithium pumping the key in changing edge stability



ELMs disappeared gradually during experiment



ELMy and ELM-free Discharges Ordered by Profile Broadening: Threshold for ELM stabilization

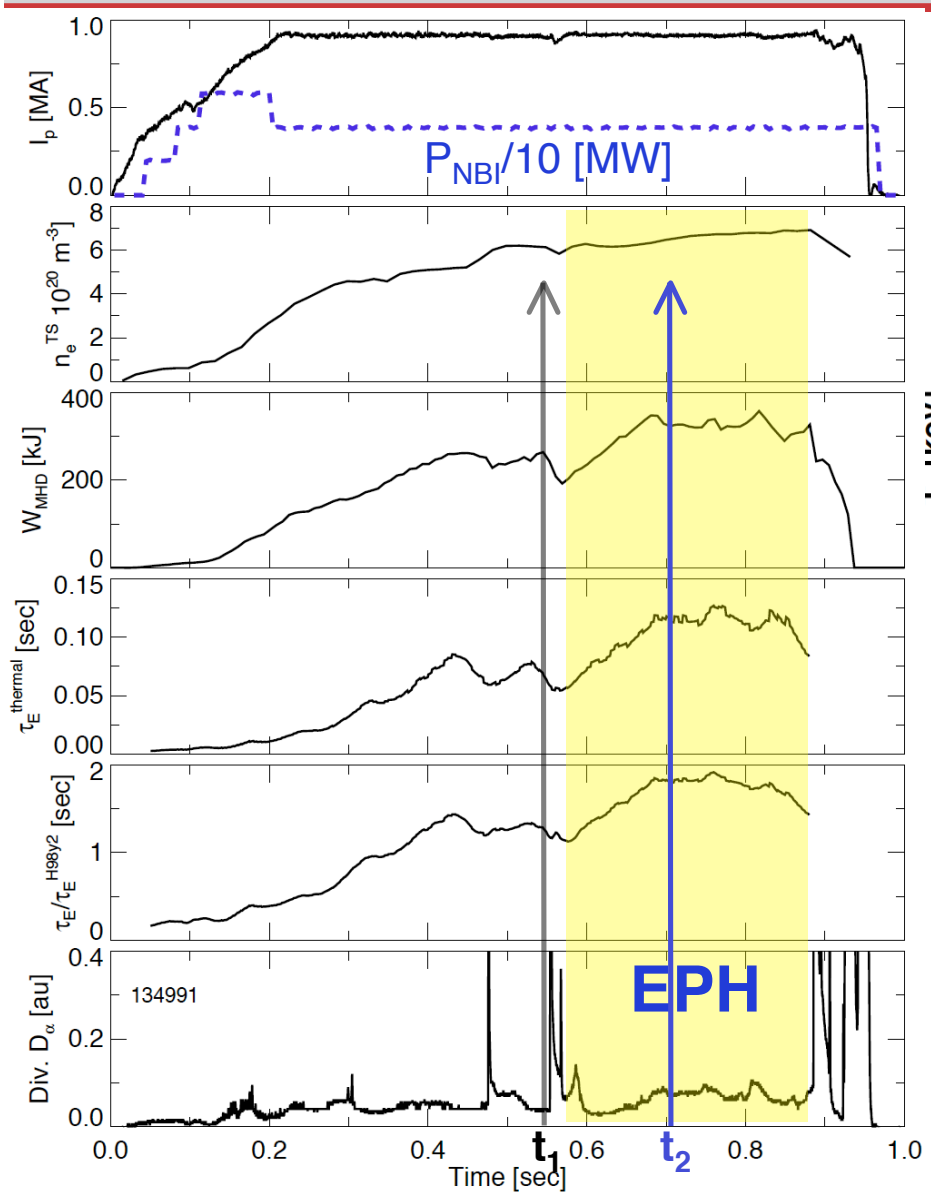


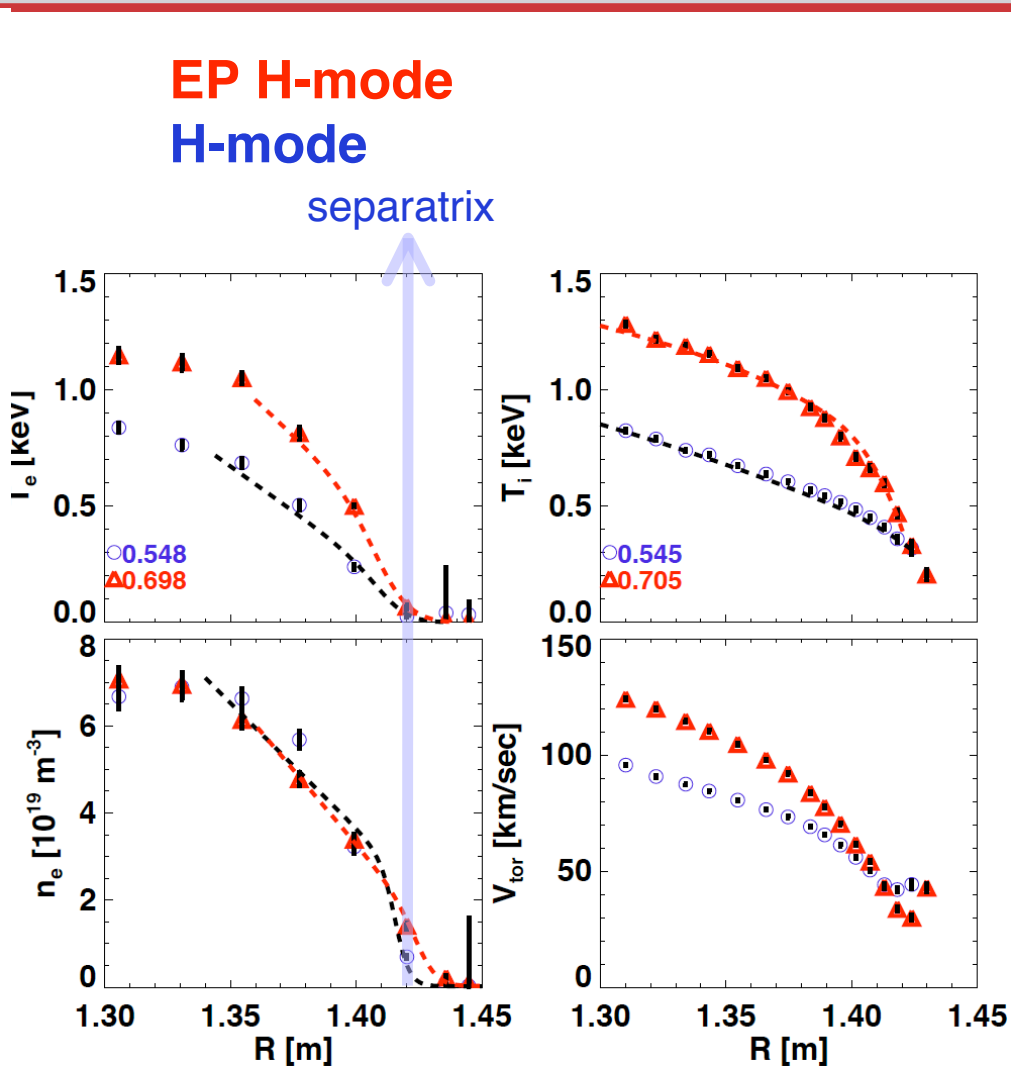
Lithium wall coatings reduce edge transport and improve ELM stability in NSTX

- ELM-free phases increase gradually with lithium deposition, with discharges eventually becoming ELM-free
  - 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
- Peak pressure gradients shifted inward -> ELMs suppressed
  - Density profile modification crucial step toward ELM suppression

- *Impurities accumulate and radiated power increases monotonically in the discharge*
  - ➢ Present remedy: use 3d fields to trigger ELMs to purge impurities while looking to reduce impurity influx, e.g. via 'snowflake' divertor

EPH-mode phase observed for several τ_E , up to ~ 300 msec





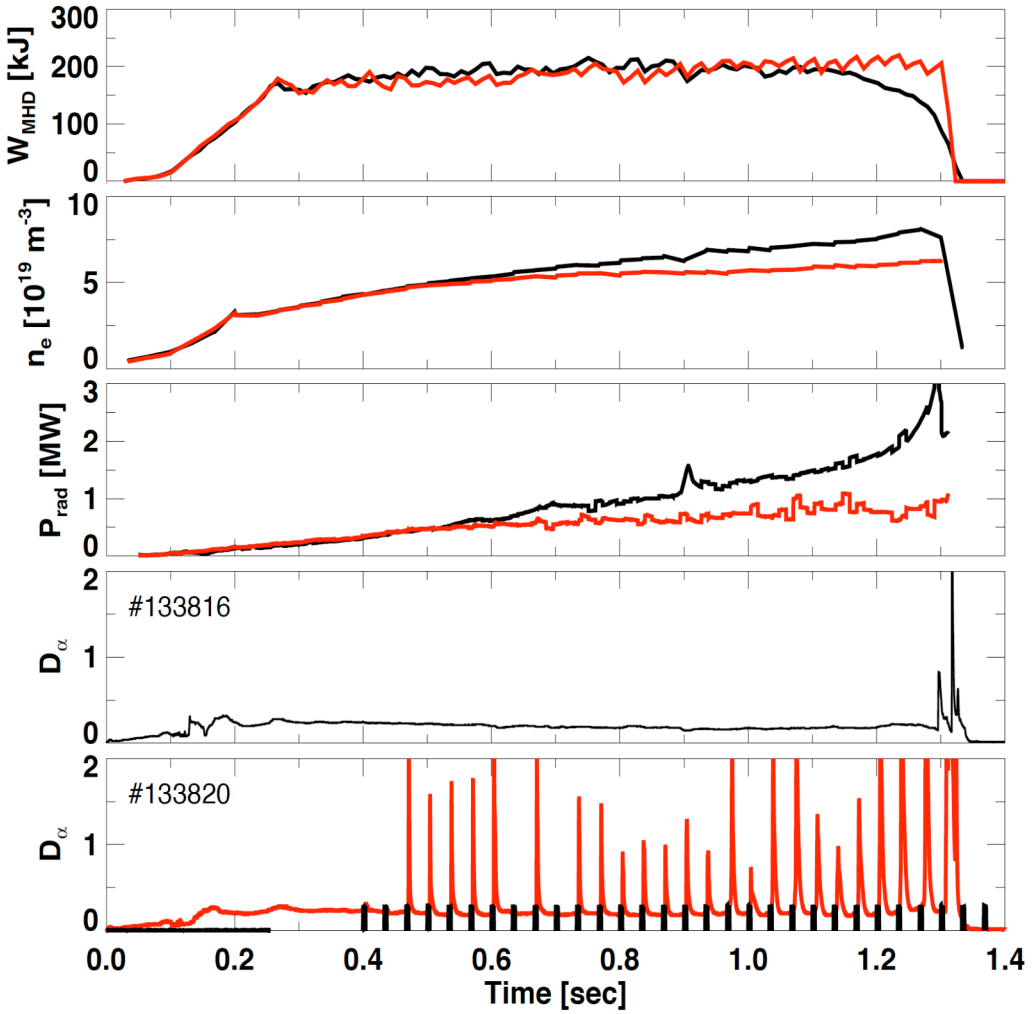
THANK YOU

FOR YOUR ATTENTION

BACKUP

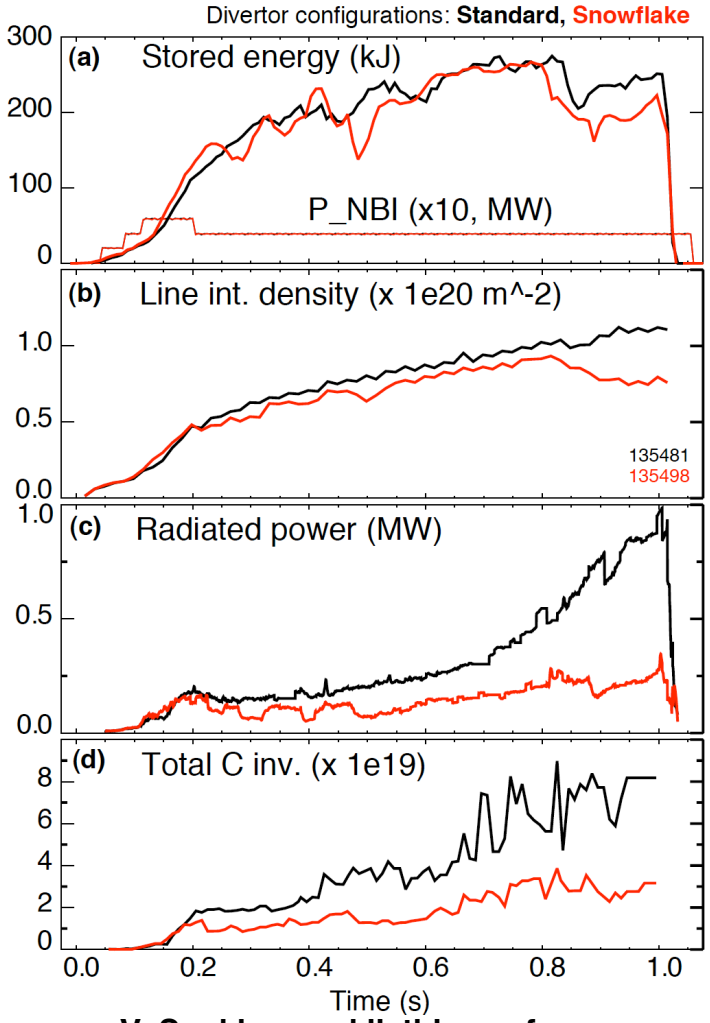
3D external fields used to trigger ELMs, prevent radiation buildup while keeping high energy confinement from lithium

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



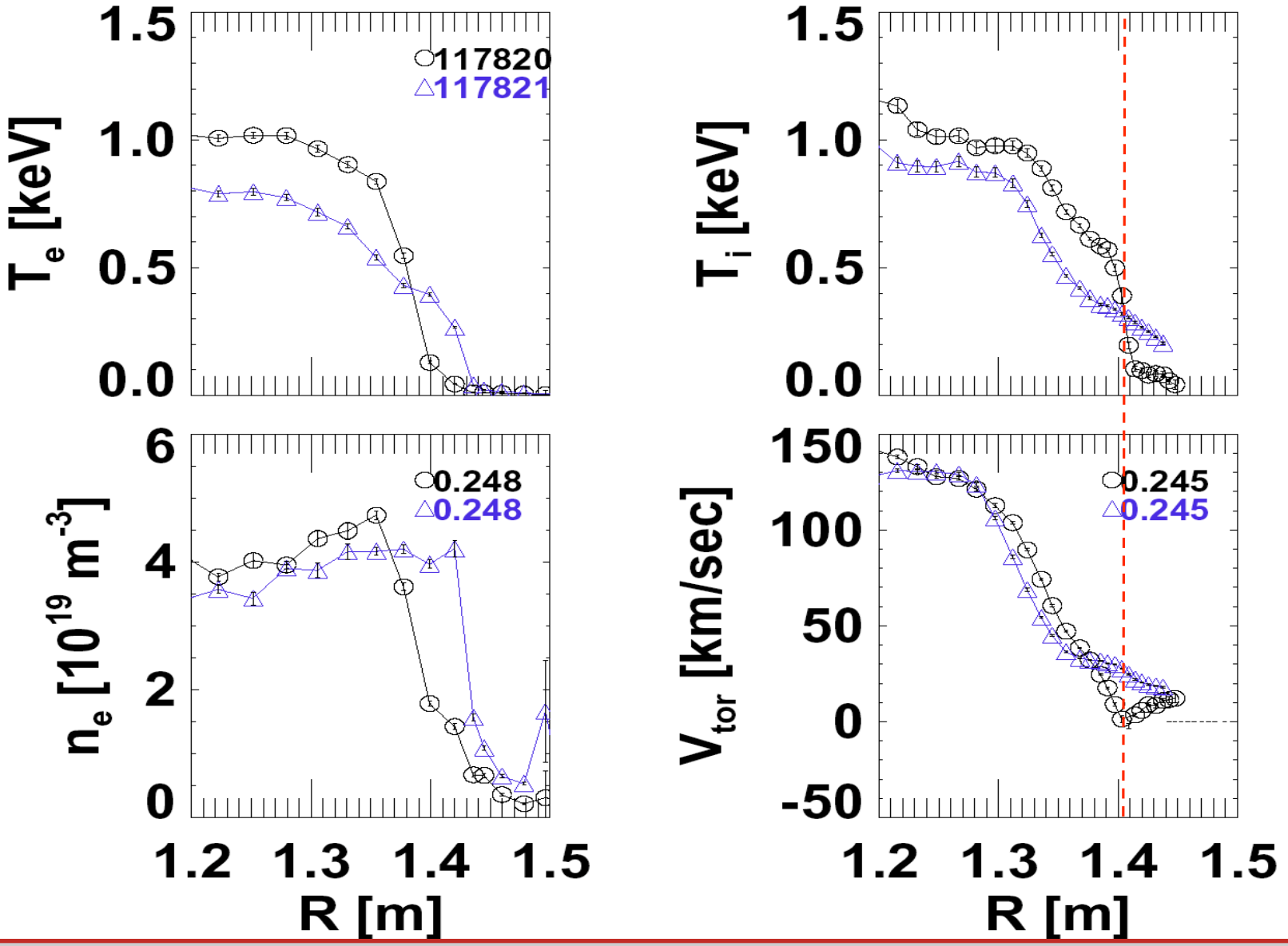
J. Canik, PRL 2010, also this conf.

"Snowflake" divertor reduced impurities



V. Soukhanovskii, this conf.

Comparison of Standard and EP H-mode profiles

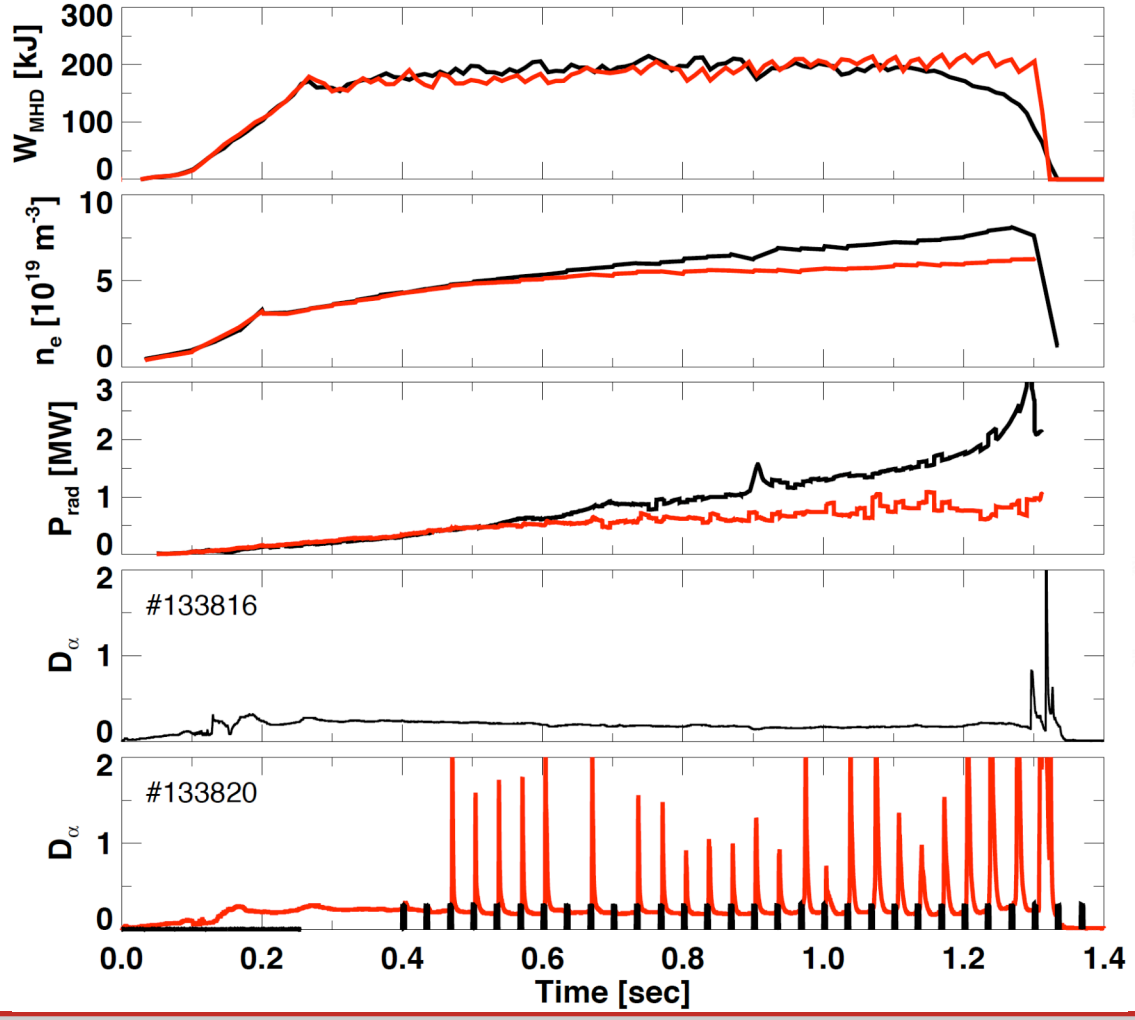


Details of ELM suppression and methods to reduce impurity buildup under active research

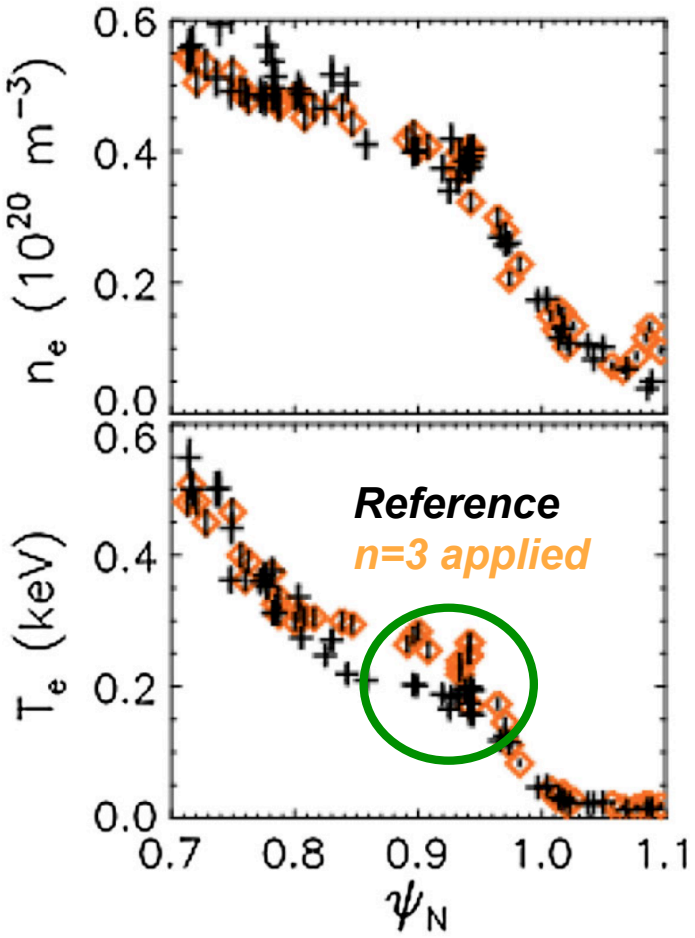
- Several outstanding questions:
  - Why are the ELMs not stabilized by diamagnetic drift, as in higher aspect ratio tokamaks?
    - Low growth rates ~ $\gamma_{lin}/\omega_A \geq 1\%$ unstable experimentally
    - Should be stabilized by diamagnetic drift: $\gamma_{lin}/(\omega^*/2) \leq 5\text{-}10\%$
  - Complete evolution: why do ELMs go away the way they do i.e. with increasing periods of quiescence?
    - Details of density/pressure profile modification may be beyond present ability to measure experimentally
      - Additional Thomson channels being installed for 2011
  - Does modification to v_ϕ profile play a role?

3D external fields used to trigger ELMs, prevent radiation buildup while keeping high energy confinement from lithium

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

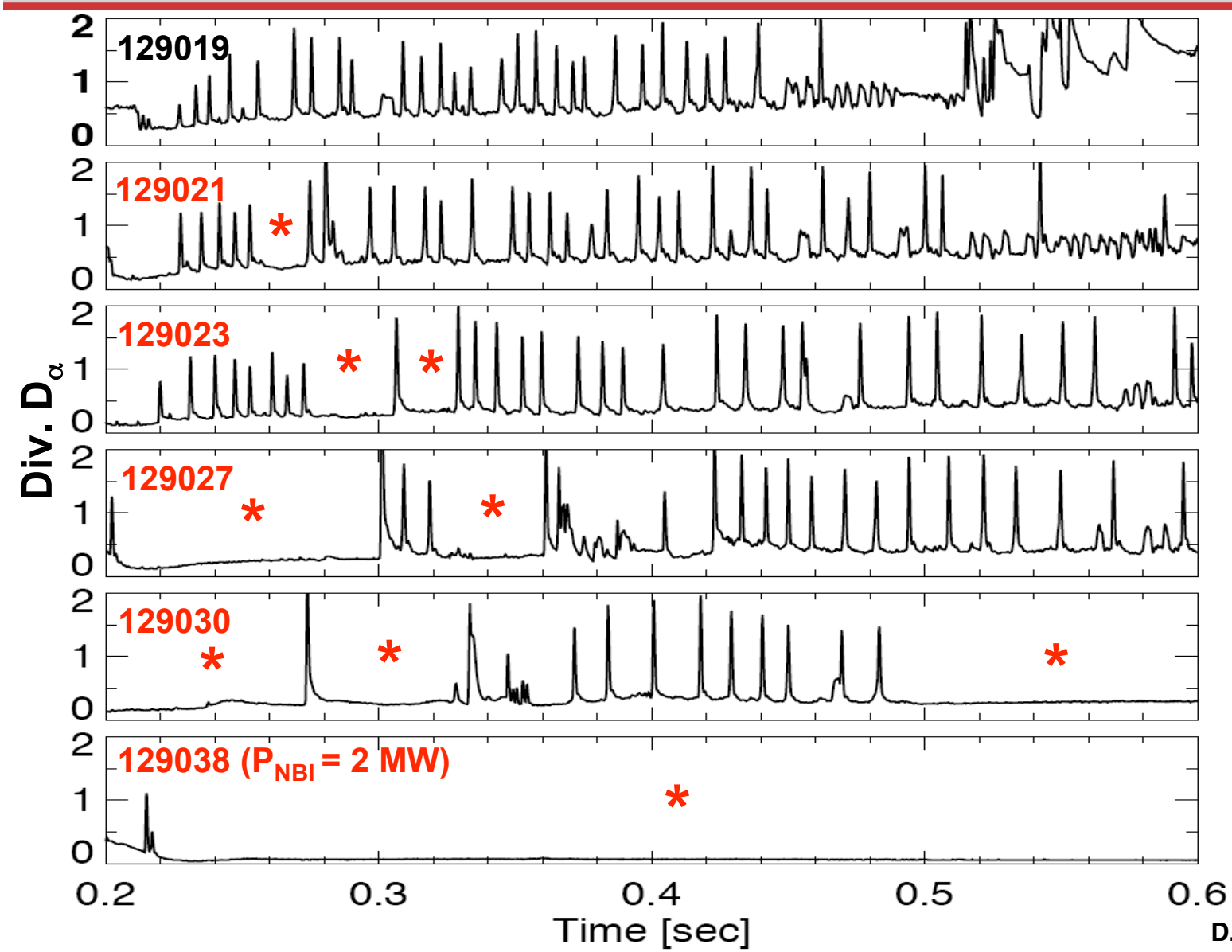


Edge T_e and dT_e/dr increased --> n=3 more unstable (PEST)



J. Canik, PRL 2010

Quiescent phases (*) increase with increasing lithium coating (P_{NBI} = 4 MW)

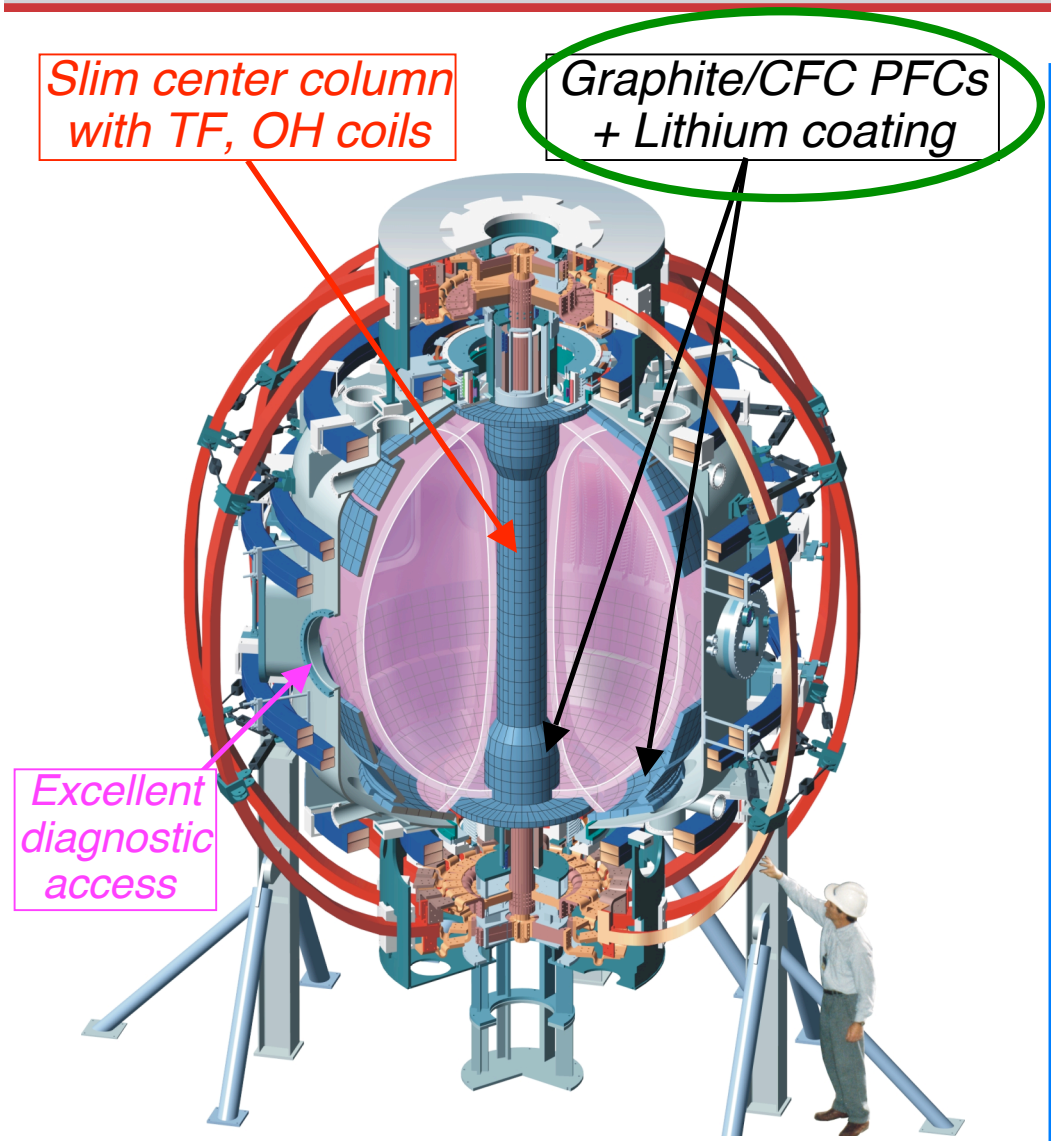


No lithium

Increasing lithium coating

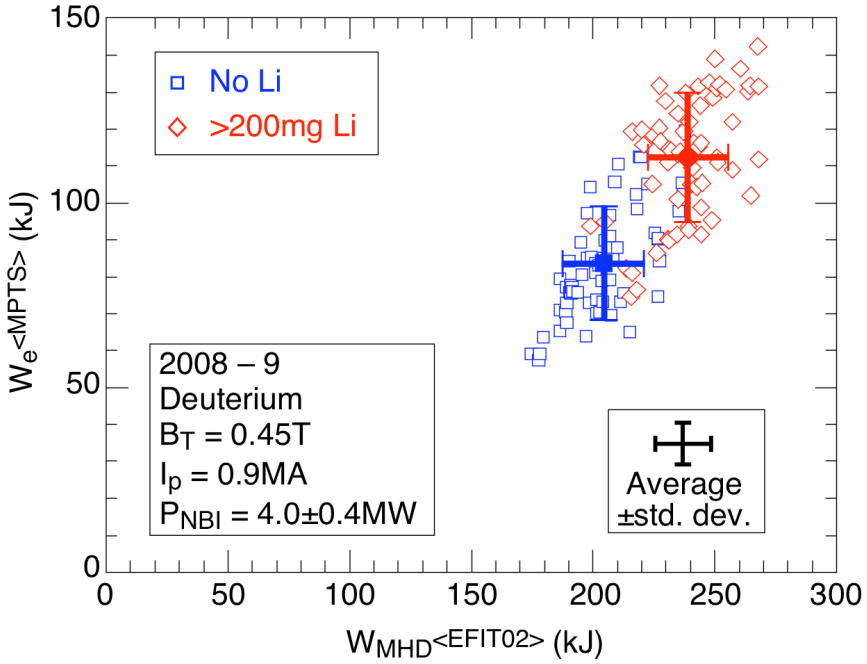
D. Mansfield, JNM 2009

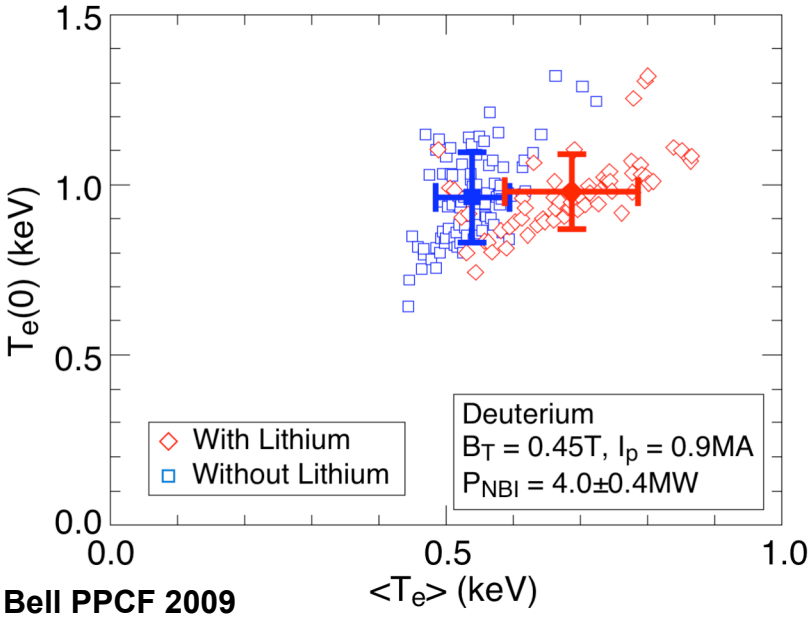
NSTX Facility Capabilities



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	$\leq 1.2\times10^{20} m^{-3}$

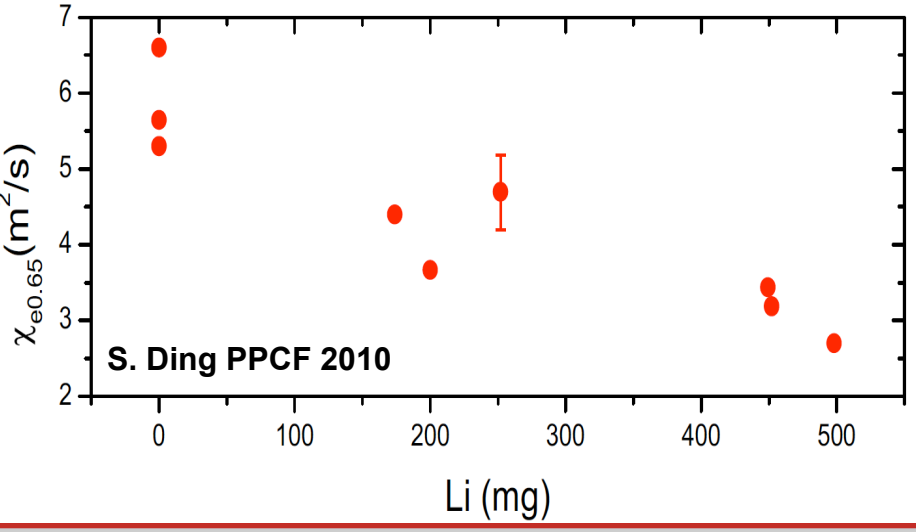
Confinement improves with lithium coatings, due to broadening of the temperature profiles





M. Bell PPCF 2009

- TRANSP analysis confirms electron thermal transport in outer region progressively reduced by lithium



NSTX Developing Lithium-Coated Plasma Facing Components (PFCs)

2005: Lithium pellet injection for wall coatings

2006: LIThium EvaporatoR (**LITER**) deposited lithium on center column and lower divertor

2007: Larger evaporator re-aimed to increase deposition rate on lower divertor

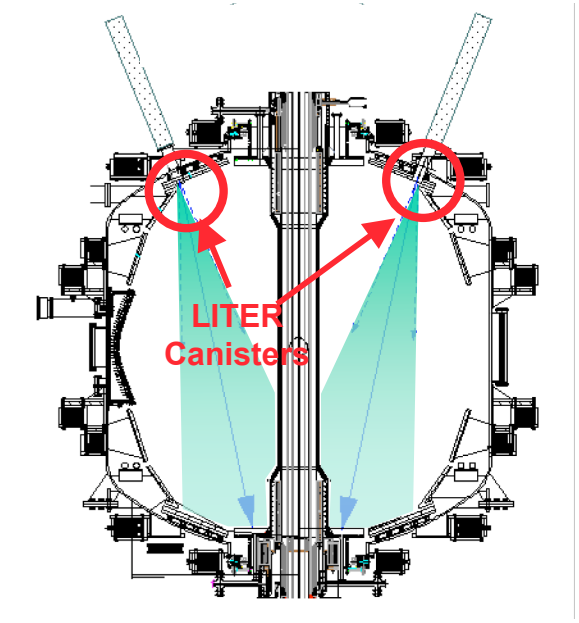
2008: Dual LITERs to eliminate shadowed regions

– Also used "lithium powder dropper"

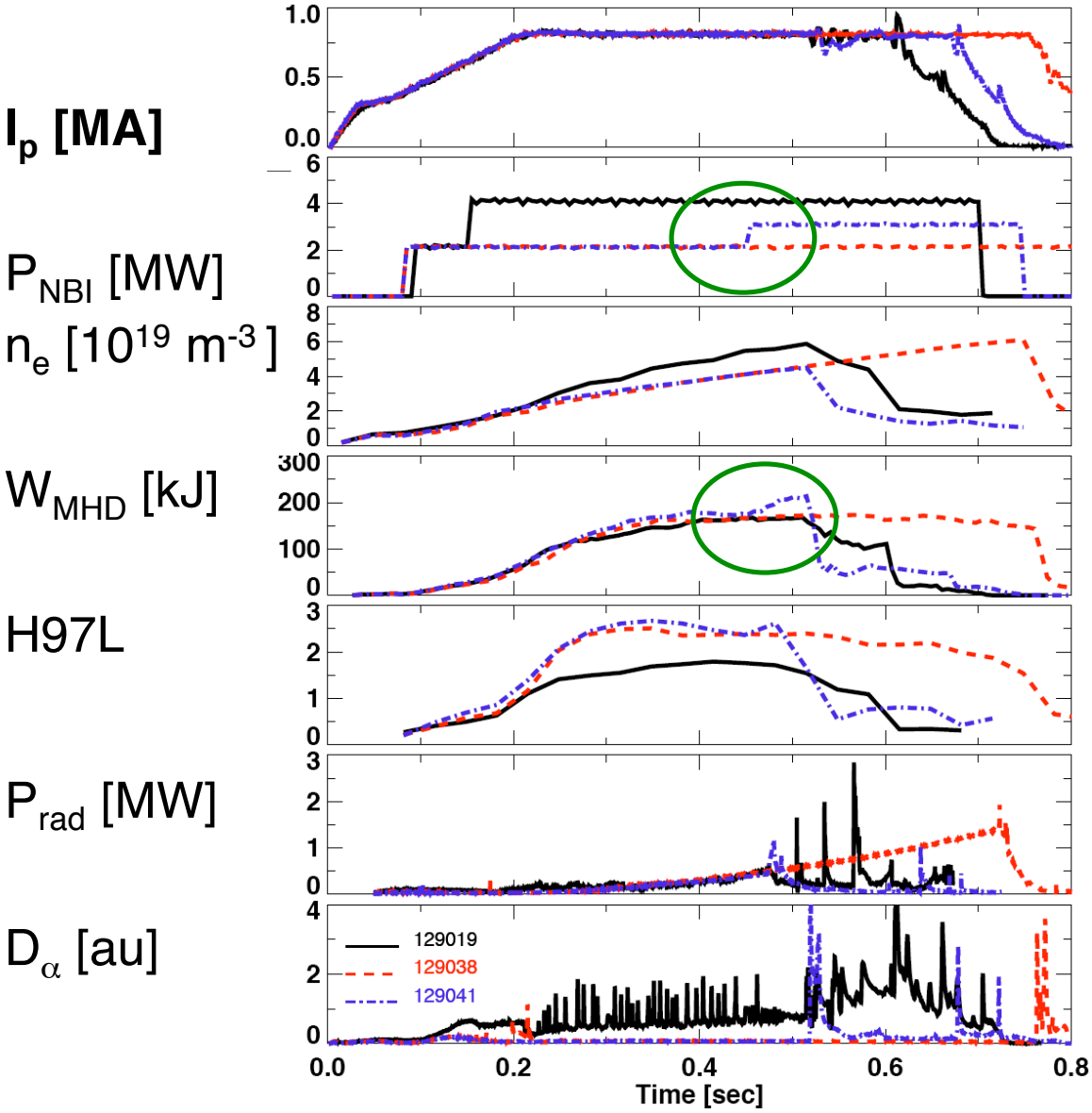
2009: Routine use of dual LITERs

- 80% of discharges now have lithium applied beforehand

- Complements and builds on experience with lithium coating of limiters in tokamaks TFTR, CDX-U (liquid), T-11, FTU, HT-7, TJ-II



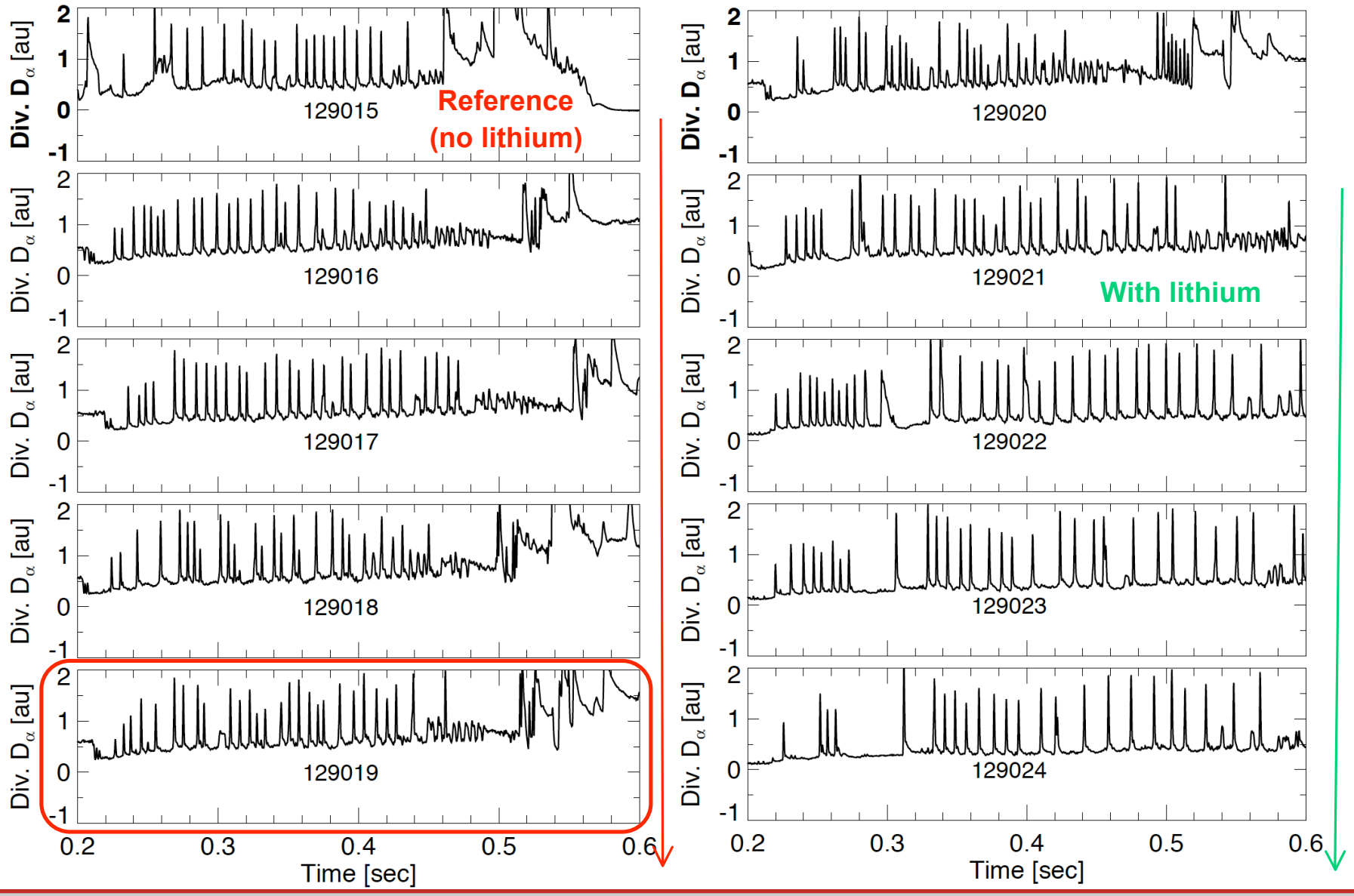
Global β_N limit encountered before edge stability limit with lithium coatings



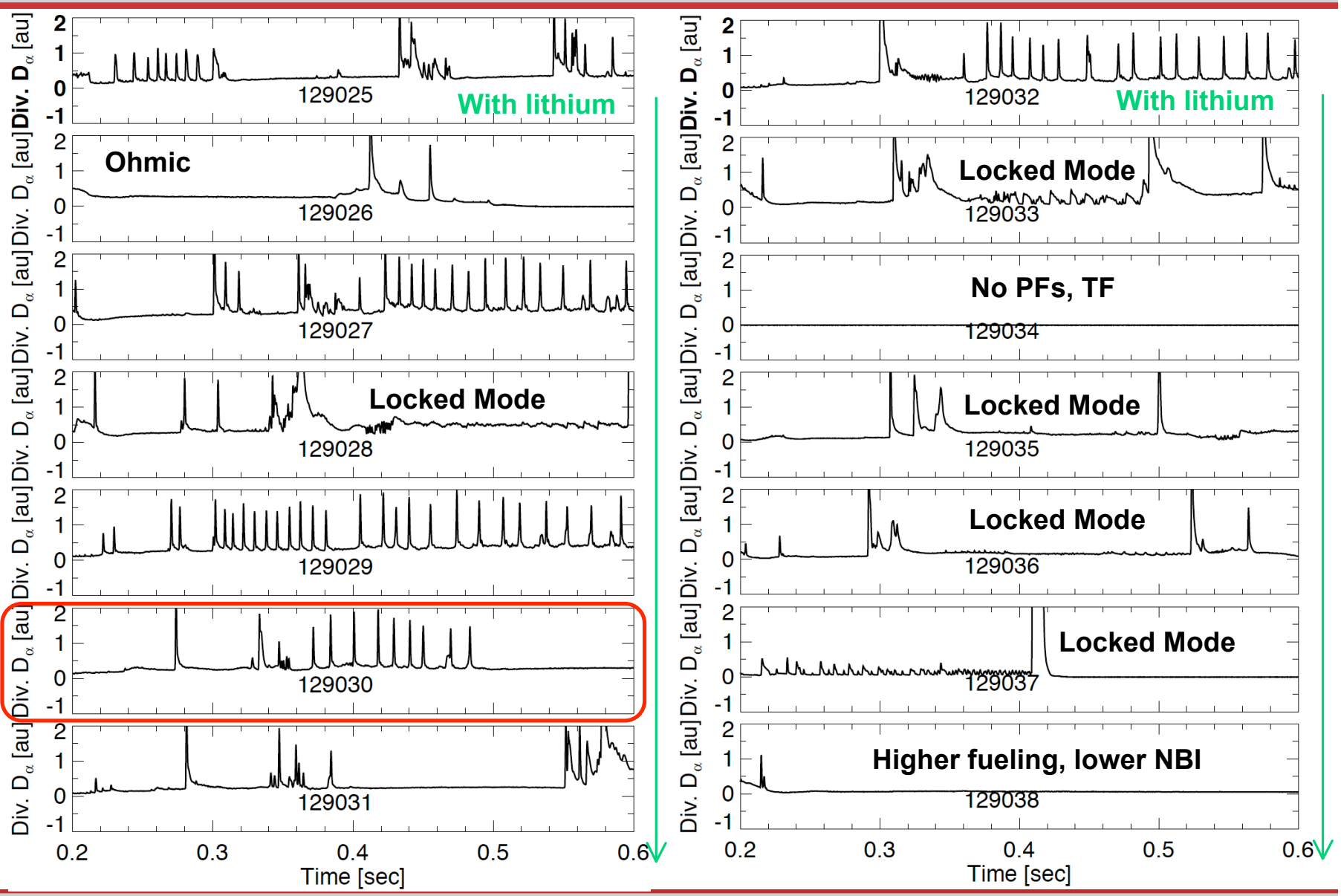
- Pre-Li, Post-li, Post-li at β limit
- Intermediate NBI to probe β limit
- β_N limit ~ 5.5 with P_{NBI}=3 MW

R. Maingi, PRL 2009

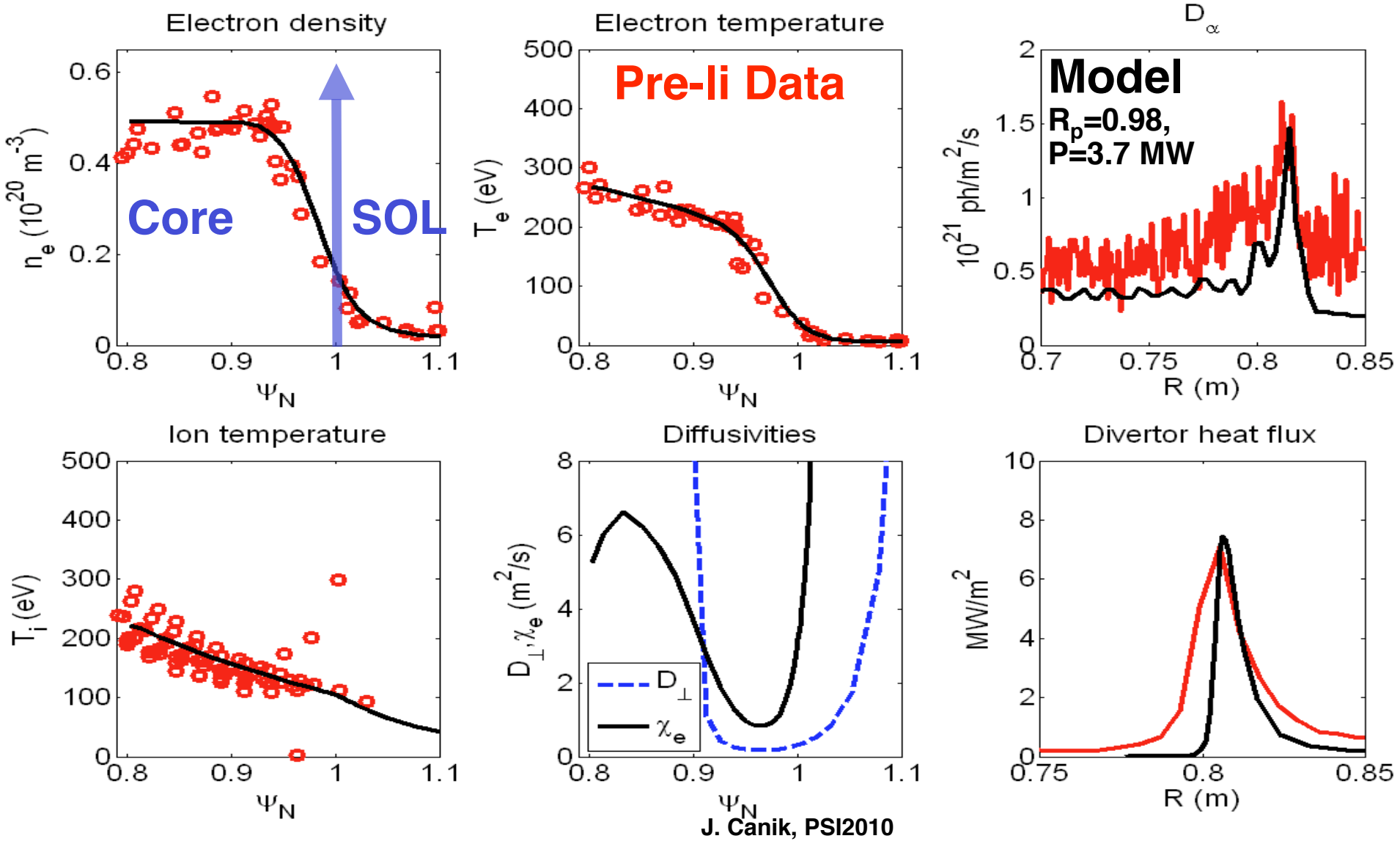
ELM evolution with shot number



ELM evolution with shot number

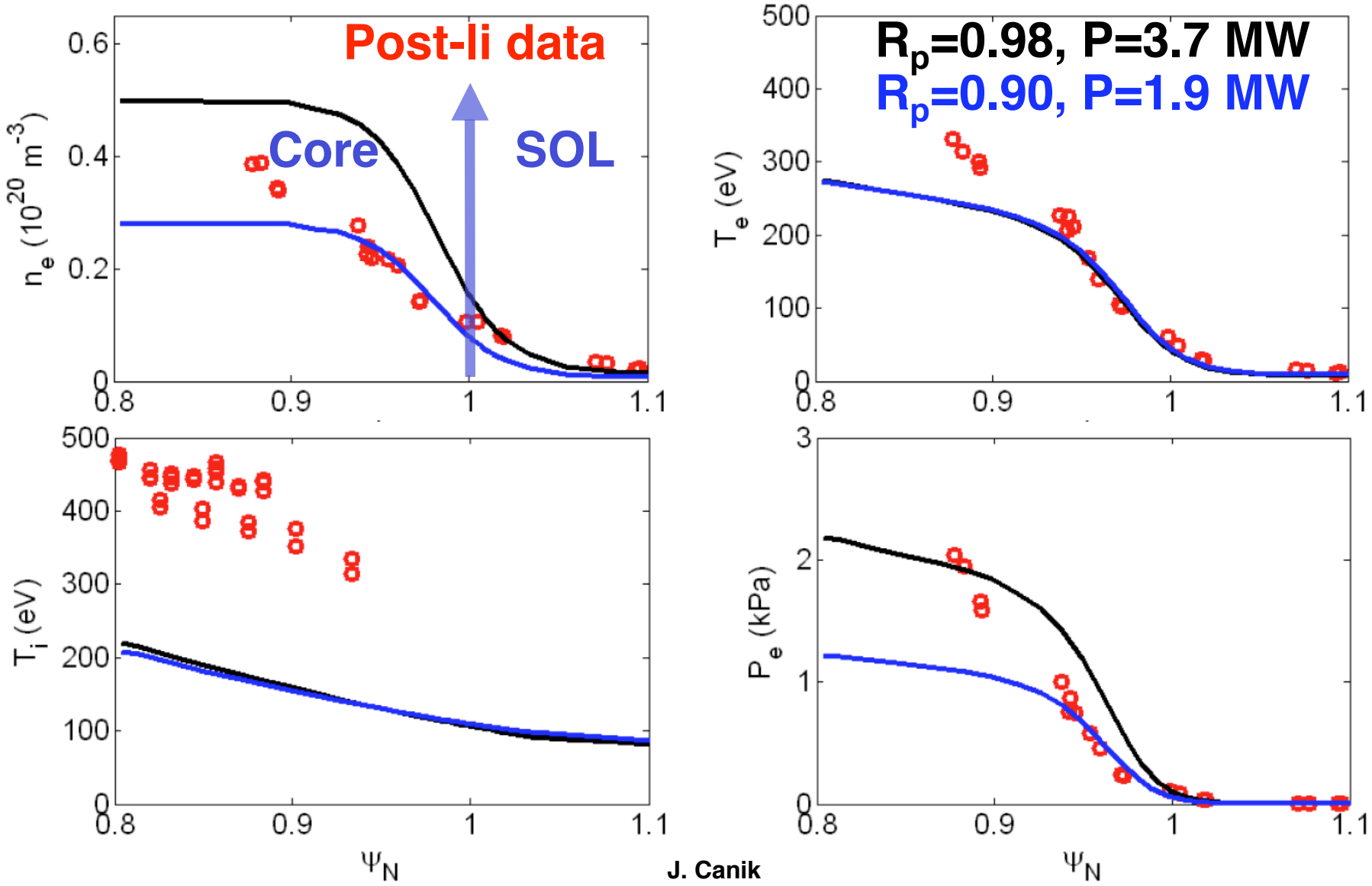


SOLPS modeling used to model power and particle balance of baseline ELMy discharge



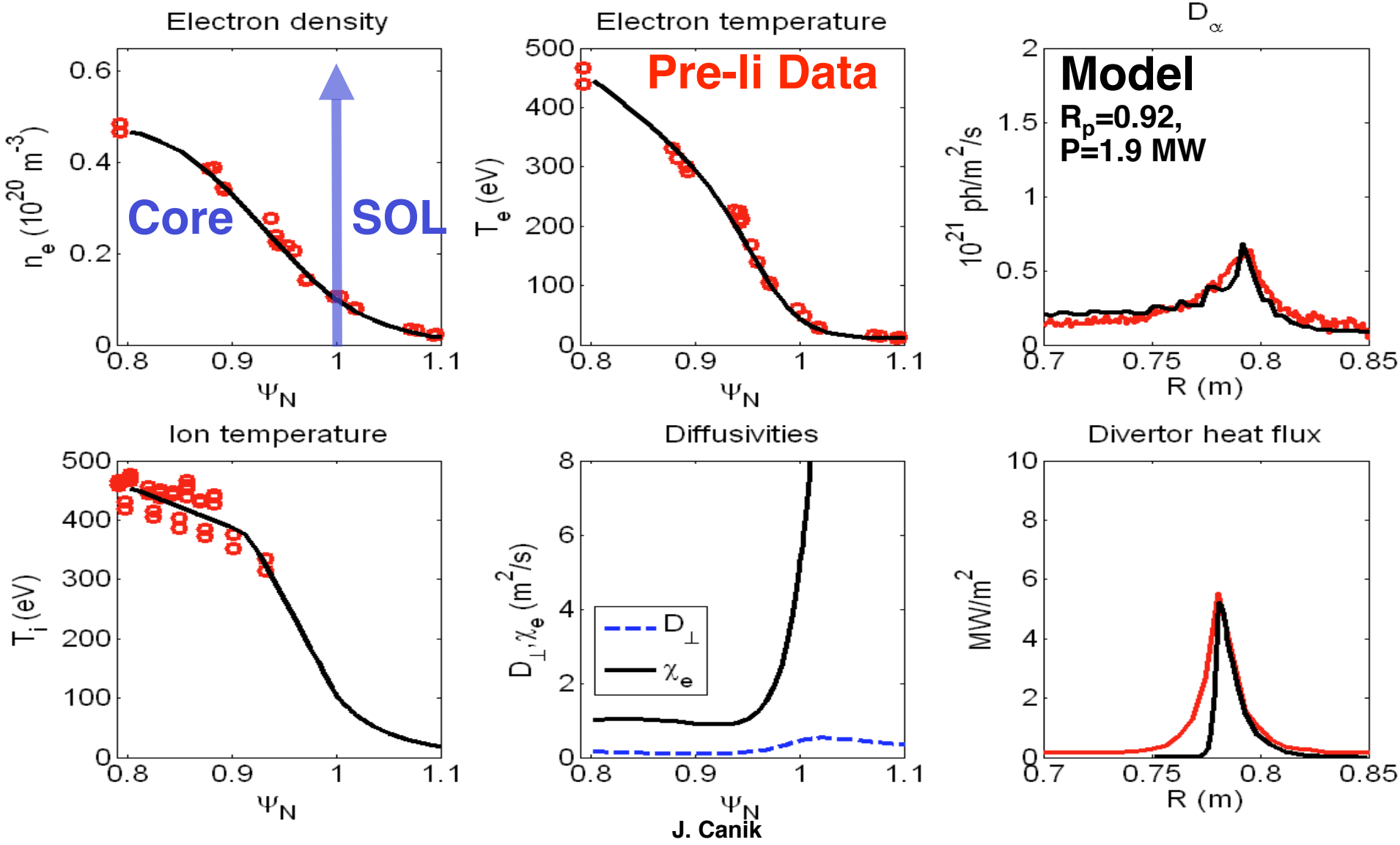
J. Canik, PSI2010

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



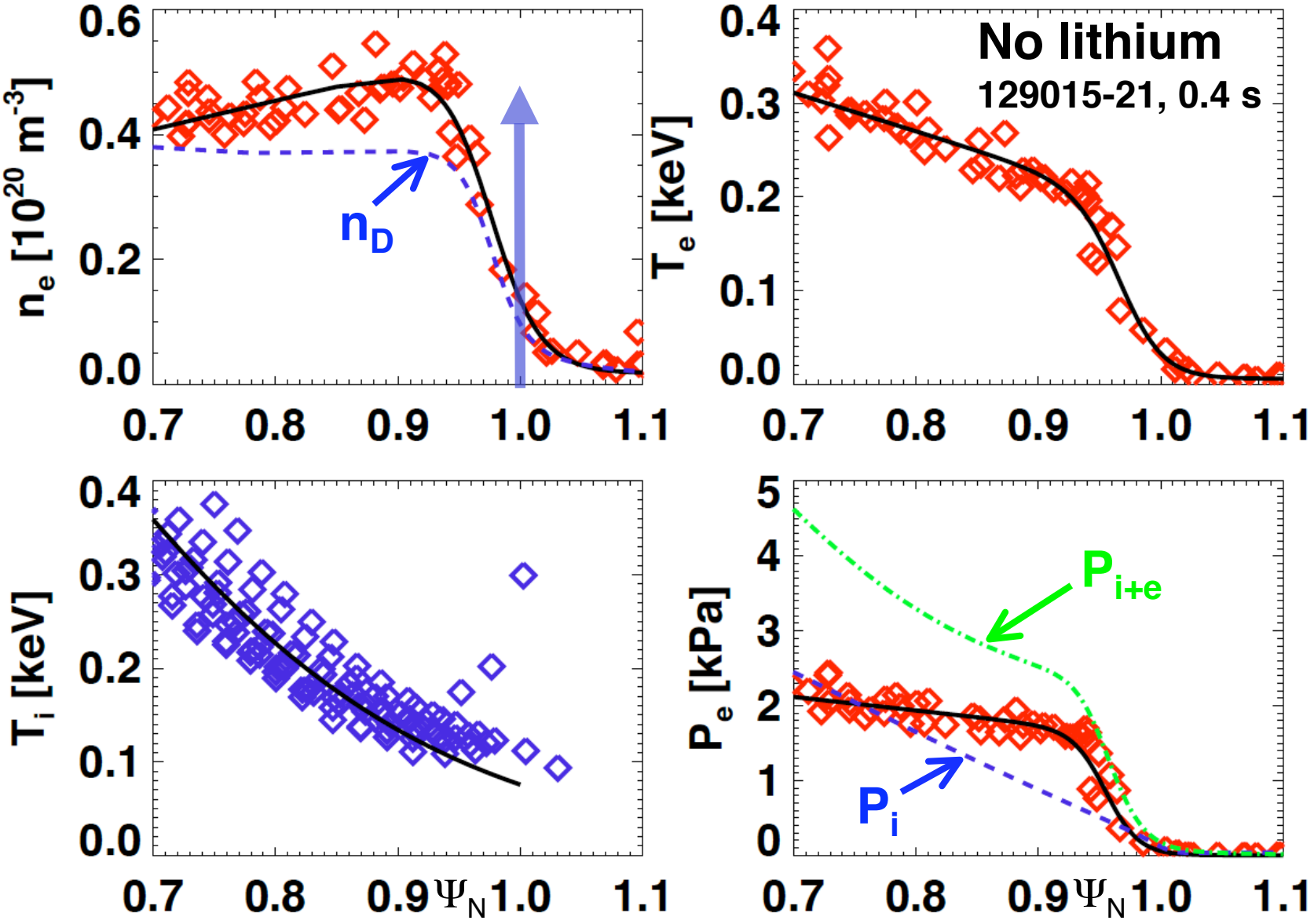
J. Canik

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

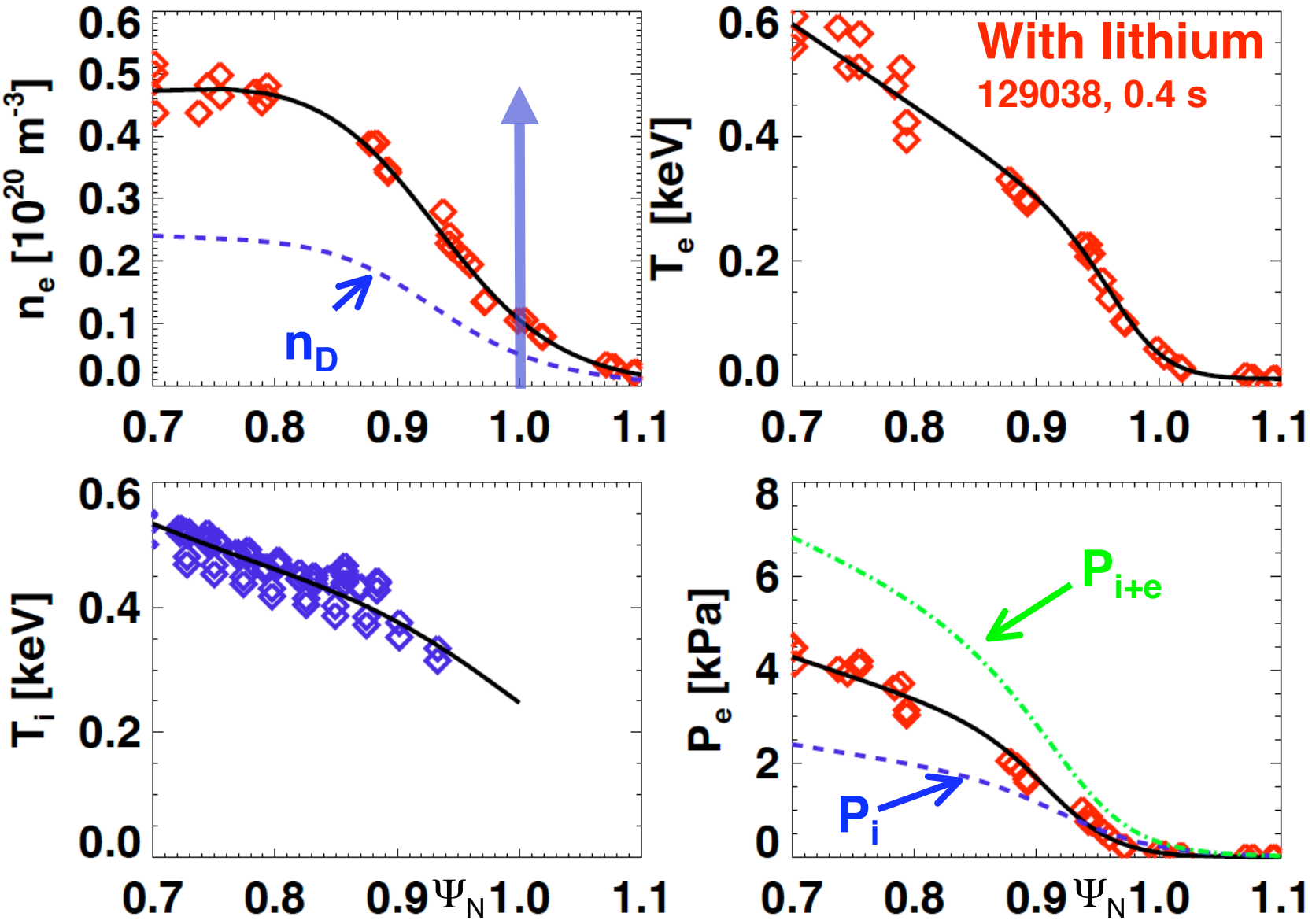


J. Canik

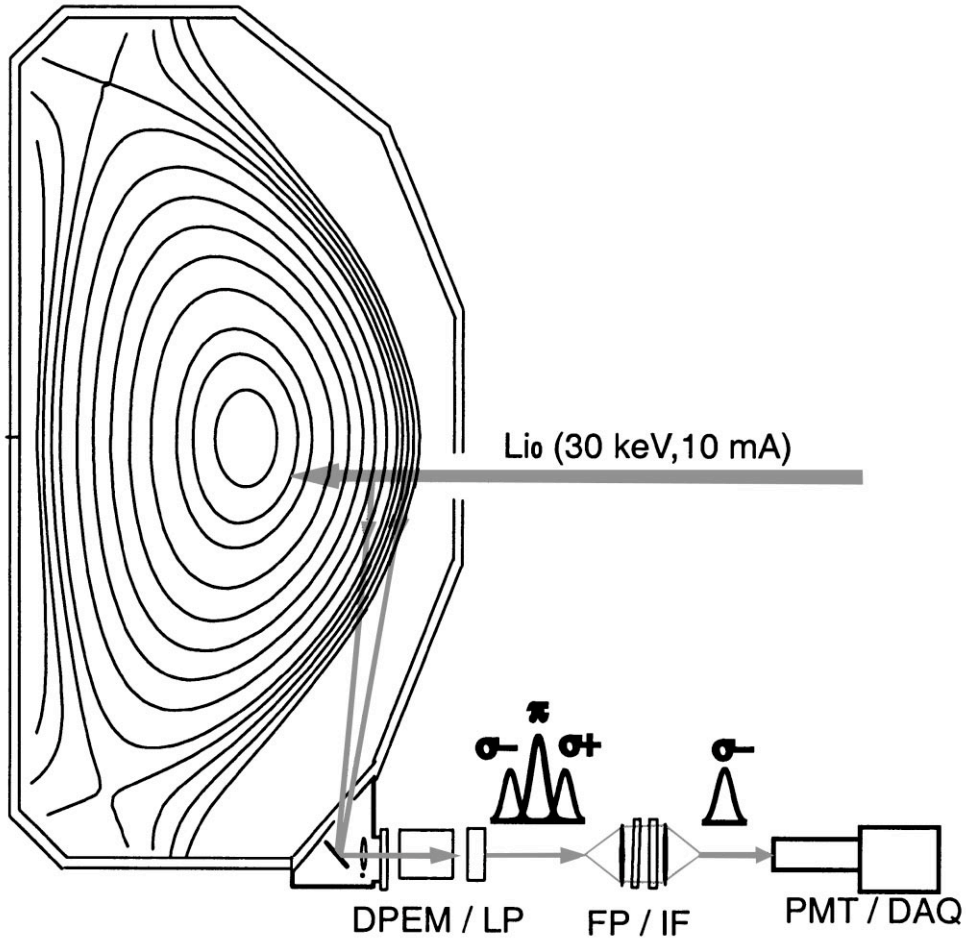
Electron pressure gradient dominates total pressure gradient



Electron pressure gradient dominates total pressure gradient



Measured edge bootstrap current in reasonable agreement with neoclassical calculation in DIII-D



D. Thomas, PRL 2004