NSTX PPPL PRINCETON PLASMA PHYSICS LABORATORY Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Research on Lithium-Coated Plasma-Facing Components in NSTX

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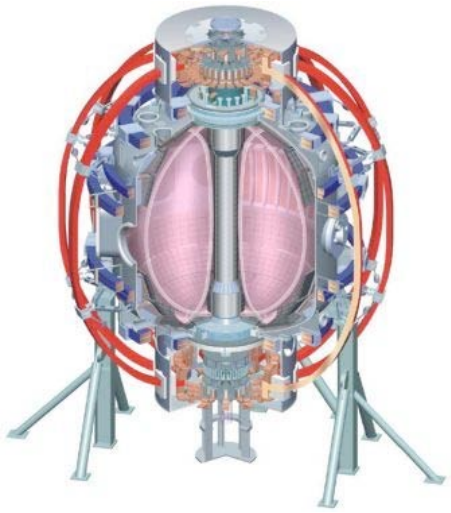
Michael Bell
for the NSTX Research Team

PPPL Theory Department Review,
September 22, 2010



Culham Sci Ctr
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NSTX has a Continuing Research Program into Effects of Lithium-Coated PFCs in *Divertor* Plasmas

2005: Injected lithium pellets (~5mg) into He discharges prior to D NBI shot

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

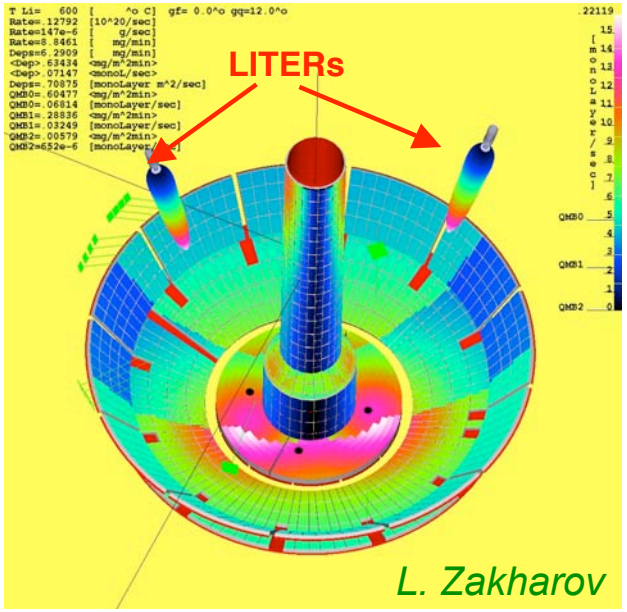
2007: Larger evaporator re-aimed to increase deposition rate on lower divertor

2008: Dual LITERs eliminated shadowed regions
– Also tried "lithium powder dropper"

2009: Routine use of dual LITERs

2010: Liquid lithium on part of lower outer divertor

Modeled 2-LITER deposition

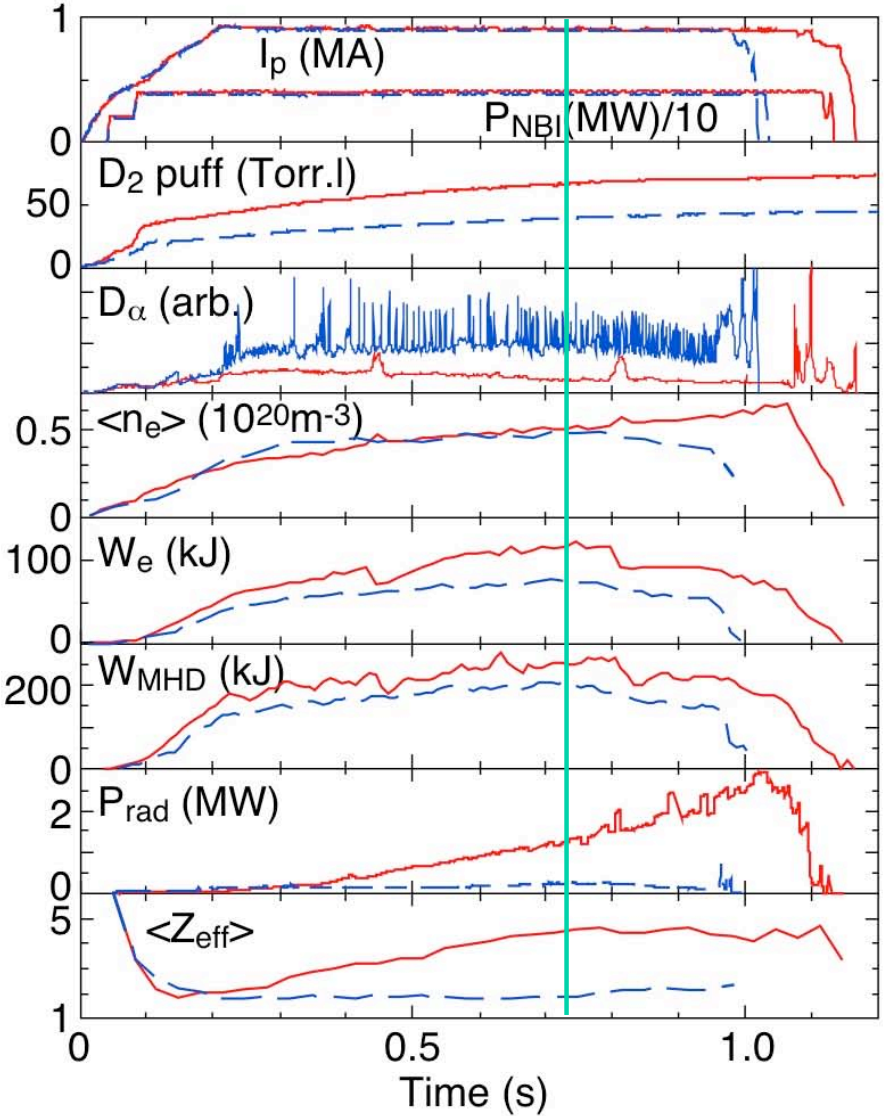


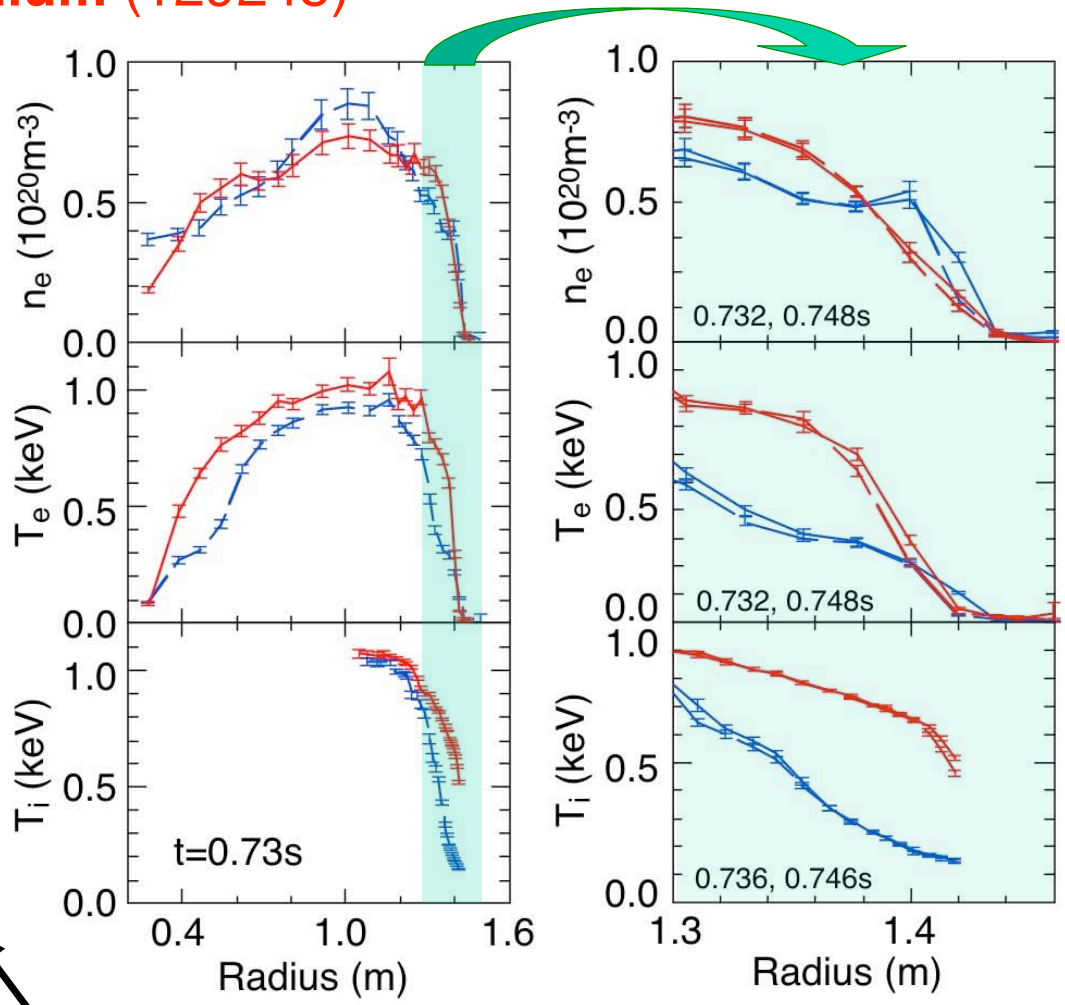
- Typically apply 100 – 600 mg lithium between discharges
  - Lithium thickness on inner divertor 5 – 160 nm

- NSTX program complements and extends lithium research on **TFTR**, **CDX-U**, **T-11**, **FTU** (limiter tokamaks), **TJ-II** (stellarator)
- Lithium research beginning on **LTX**, **HT-7**, **EAST** (divertors) and **RFX** (RFP)

Lithium Coating Reduces Deuterium Recycling, Suppresses ELMs, Improves Confinement

No lithium (129239); **260mg lithium** (129245)

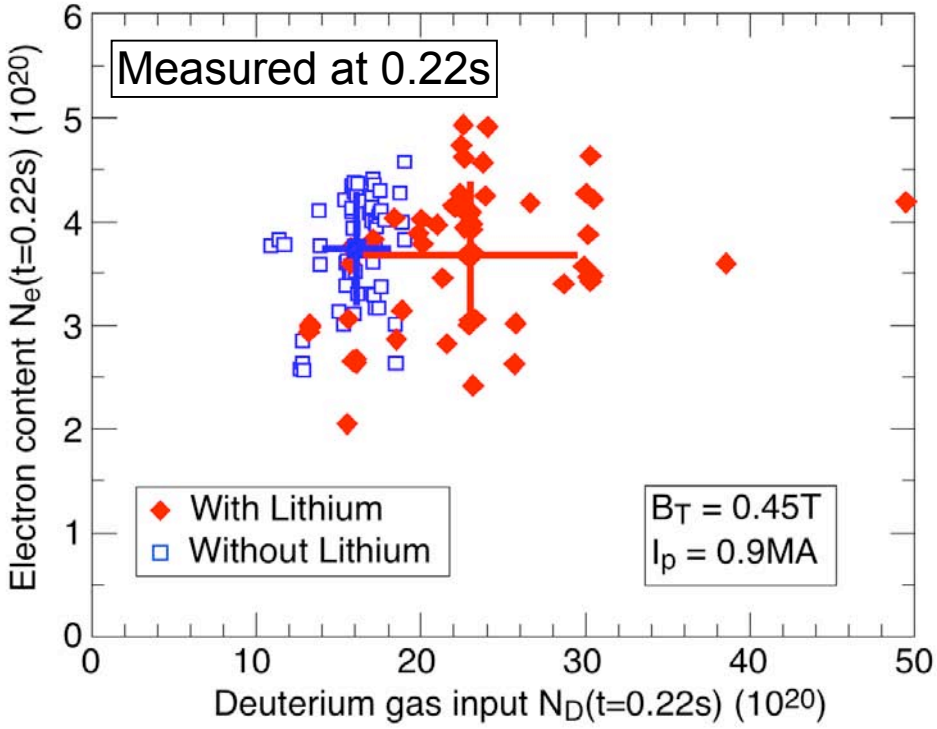




Without ELMs, impurity accumulation increases radiated power and Z_{eff}

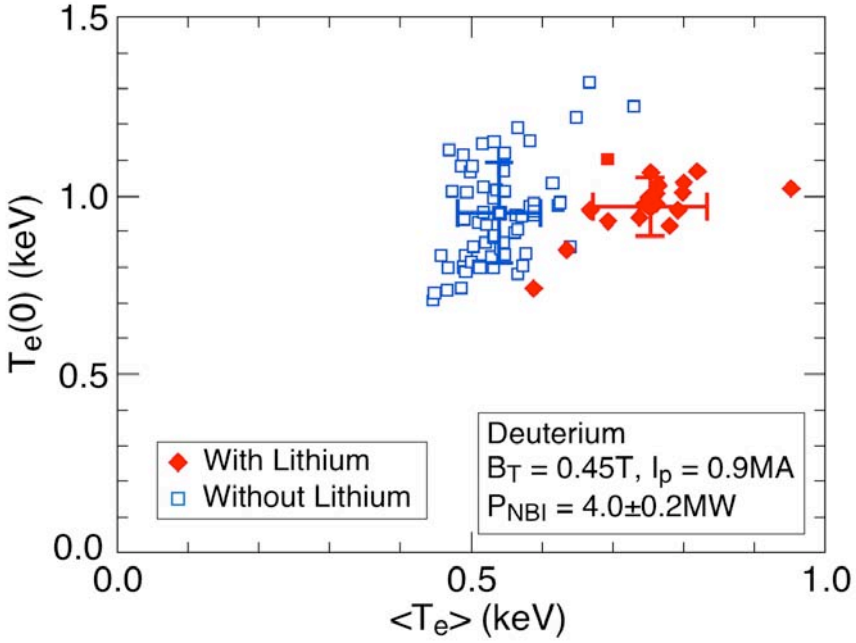
Although Lithium Reduces Deuterium Recycling, Need to Increase Fueling to Avoid Locked Modes

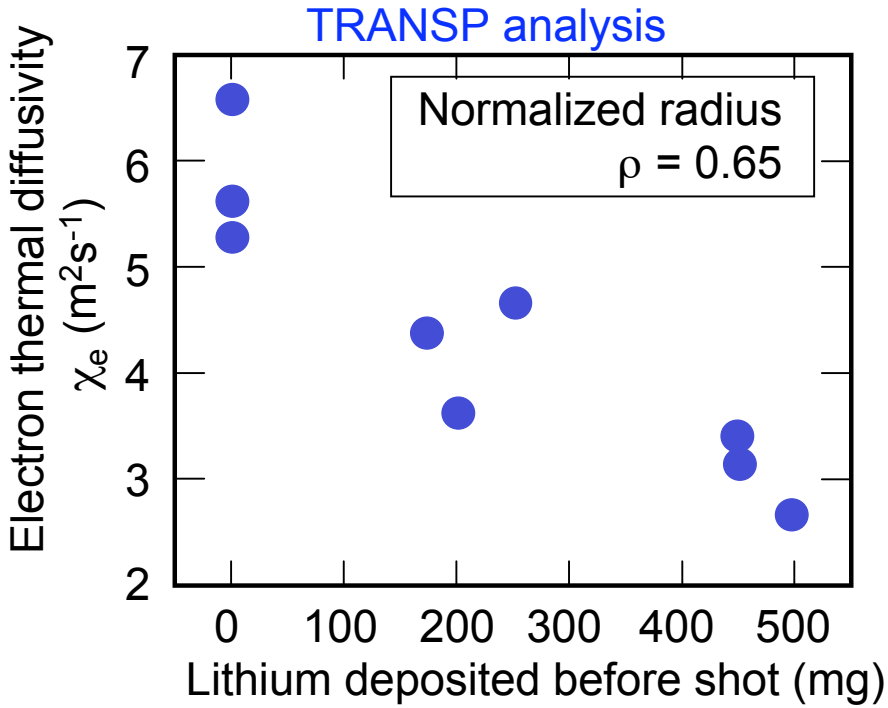
- Measurements of D_α emission profile show greatly reduced neutral D density across outboard midplane with lithium
- Lower density achievable early in discharges both with and without lithium but likelihood of deleterious locked modes increases
  - Lower density desirable to achieve NSTX goal of non-inductive sustainment



- ***MHD stability of low-density shaped plasmas a critical issue***

Broadening of Electron Temperature Profile Implies Reduction of Thermal Diffusivity in Outer Region



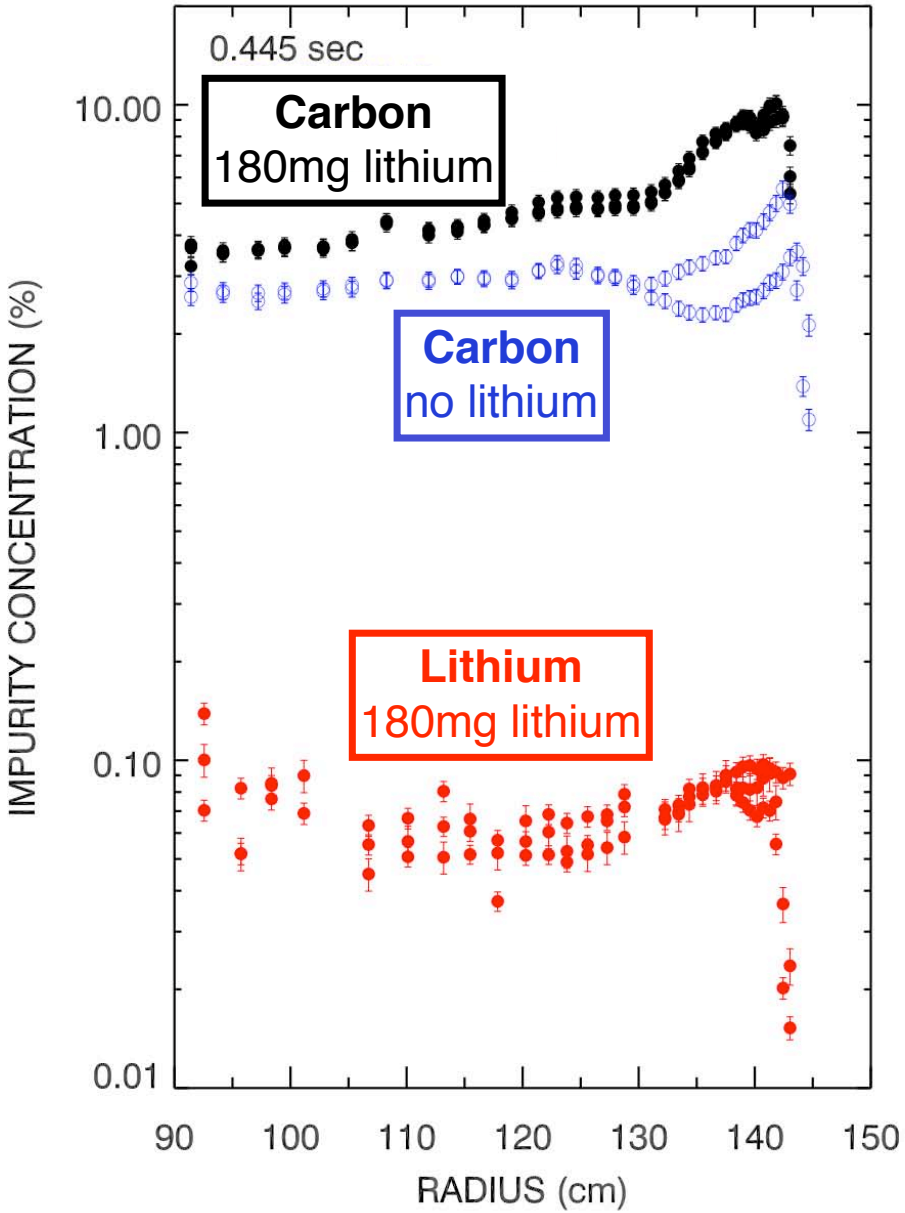


- All plasmas, both with and without lithium, in H-mode
- H-mode threshold reduced by lithium coating by up to factor 4
- Fast-ion contribution to total energy ($\propto T_e^{3/2}/n_e$) also increases
- Thermal ion confinement remains close to neoclassical level both with and without lithium

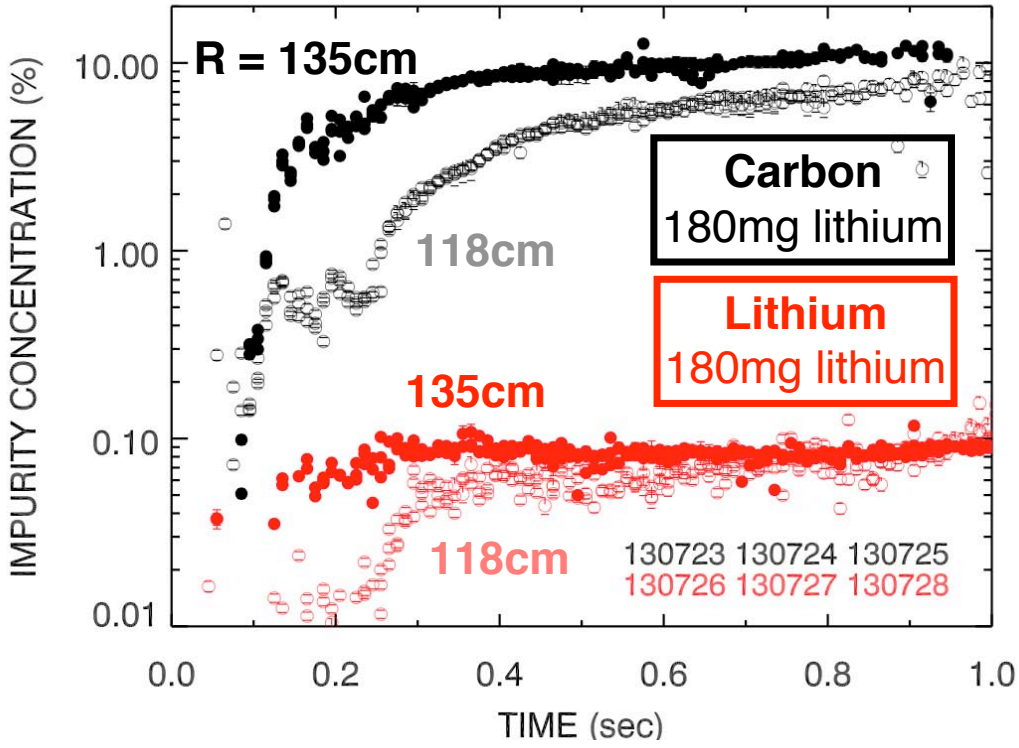
Improved Confinement Provides Opportunities for Theoretical Explanation and Model Testing

- In TFTR, improvement with lithium was in the "supershot" regime
  - Anomalous transport associated with ITG turbulence: $T_{i,max}(0) \propto T_i(a)$
  - Lithium reduced recycling below what was achievable with "conditioned" carbon PFCs allowing higher edge temperature *and*
  - Larger E/B shearing with peaked p(r) stabilized modes for $\omega_{EXB} > \gamma_{ITG}$
  - Electron temperature profile also broadened with lithium coating
- Also note theoretical predictions of enhanced ion neoclassical transport driven by cold ions from edge [A.A. Ware, PFB **2** (1990) 1435]
- In NSTX, transport appears to be reduced in electron channel
  - Ion transport already close to neoclassical: high E/B shearing at lower B
  - Suppression of ETG modes has been associated with reduced χ_e in NSTX reversed-shear plasmas *but*
  - We do not have measurements confirming ETG suppressed by lithium
  - T_e profile is tending towards predictions of flat T_e with fully absorbing wall

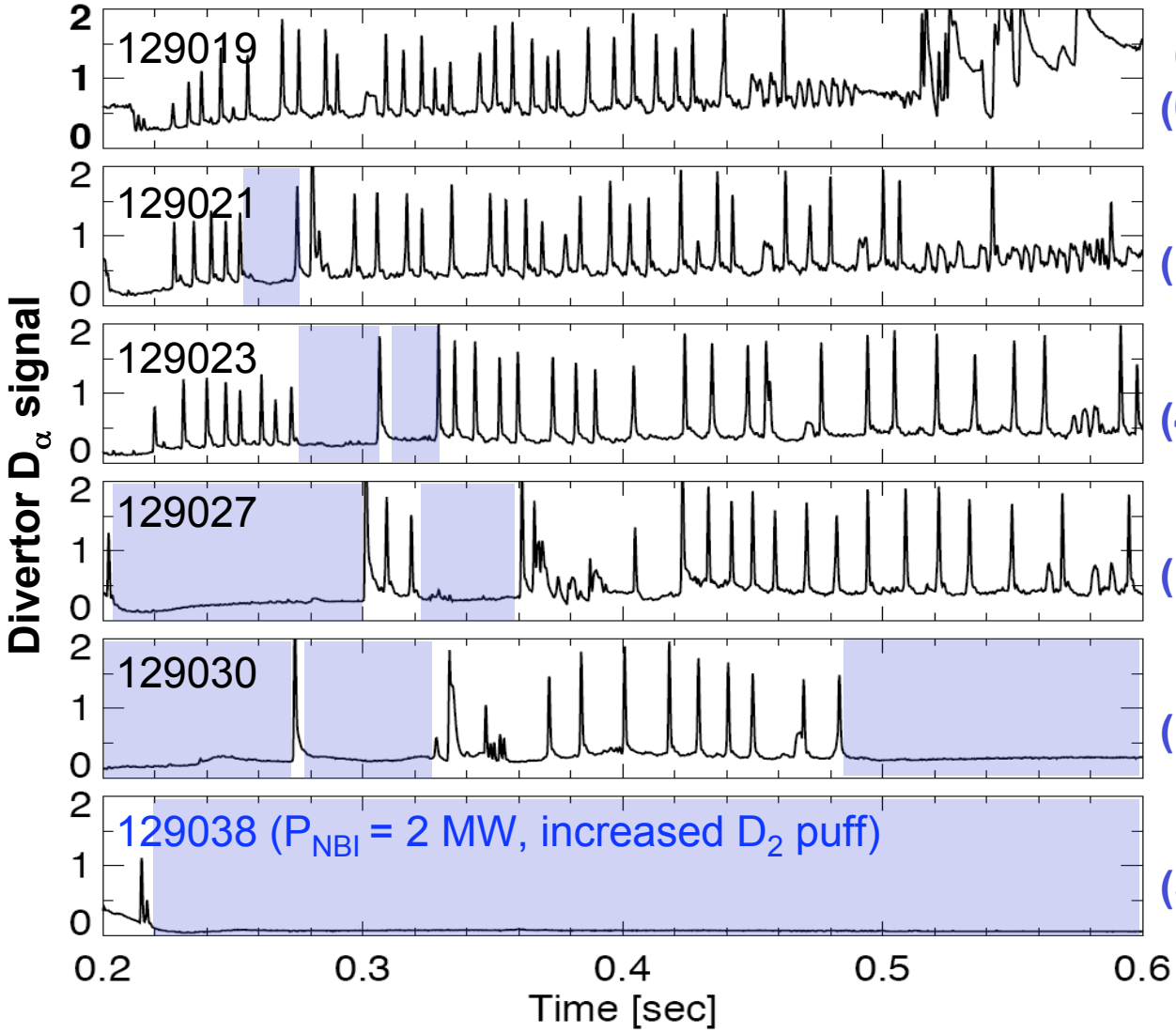
Lithium Concentration in Plasmas Remains Low but Carbon Concentration Rises with Lithium Coating



- Quantitative measurements of C^{6+}, Li^{3+} with charge-exchange recombination spectroscopy
- **n_C/n_{Li} = 30 – 100**
- Hollow profiles early for both C and Li fill in as time progresses



Suppression of ELMs Occurs By Lengthening and Coalescence of ELM-free Periods



0 **Lithium deposited**
(0) **(accumulated) (mg)**

110
(110)

150
(426)

170
(1056)

264
(1624)

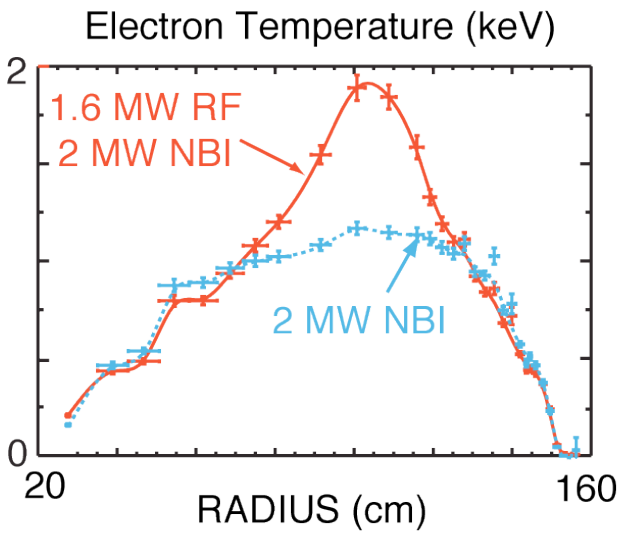
715
(5355)

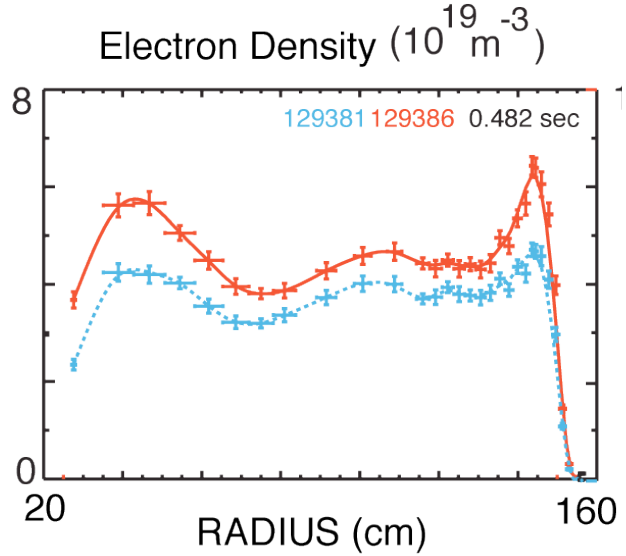
- Shots with I_p = 0.8 MA, B_T = 0.5T, P_{NBI}= 4 MW
- All shots remain in H-mode

- ELM suppression was predicted through changes in location of current density gradient with respect to mode rational surfaces (Zakharov, 2006)

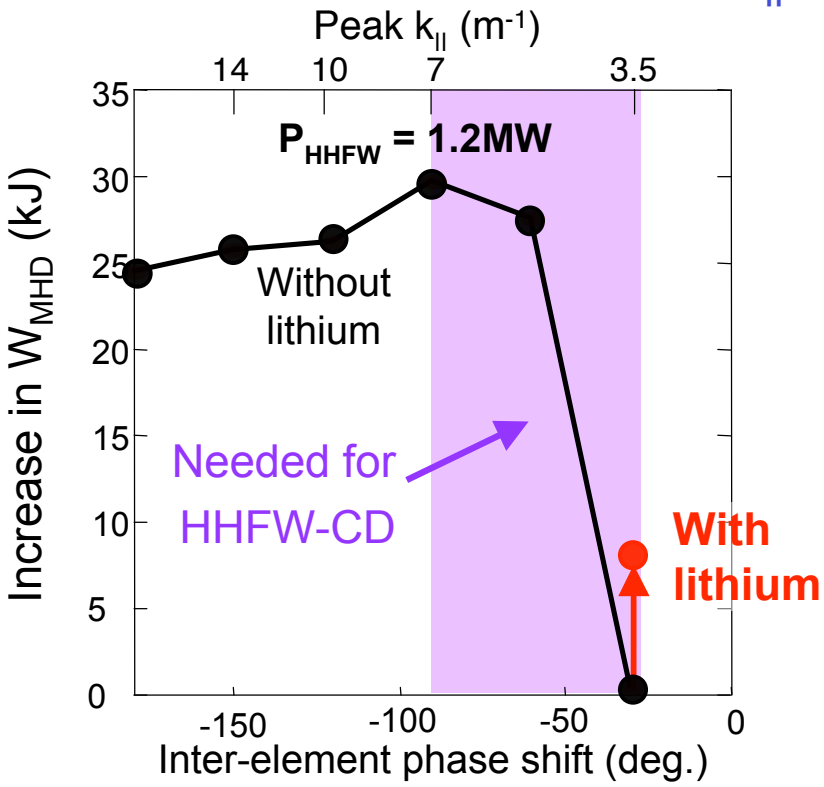
Lithium Coating Improves HHFW Heating Efficiency in NBI H-Modes and at Low $k_{||}$ for Current Drive

Core Electron Heating in Deuterium NBI H-Mode





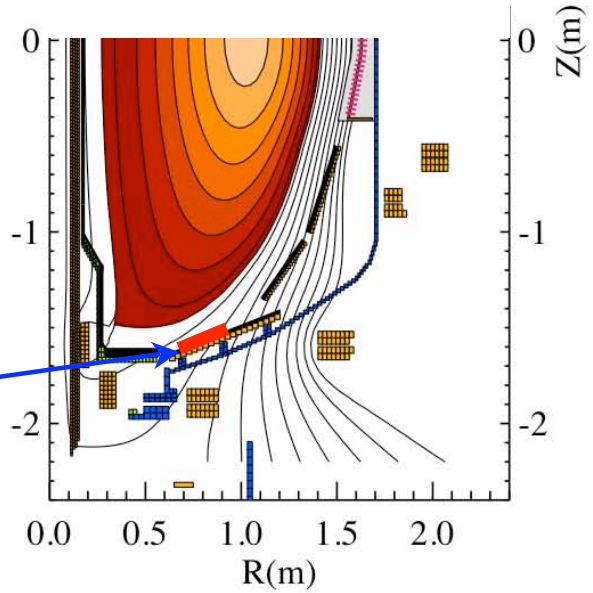
First indications of heating at low $k_{||}$ in D



- Reflectometer measures reduced SOL density in front of antenna with lithium
  - Results consistent with suppression of parasitic surface waves in SOL
    - $n_{e,SOL} < n_{e,crit} \propto B\, k_{||}^2 / \omega$

This Year, NSTX Began Investigating *Liquid Lithium* on Plasma Facing Components

- Laboratory measurements in PISCES and experience in CDX-U show that liquid has much higher capacity for deuterium retention than solid



- Replaced carbon tiles in outer lower divertor with 4 segmented plates
  - Plasma-facing surface coated with semi-porous (~50%) molybdenum
  - Surface could be heated to >300°C (Li melting point 180°C)
  - Supplied lithium with LITERs and lithium powder dropper
- Initial experiments designed to evaluate capability of liquid lithium to sustain deuterium pumping
  - Small differences observed so far at variance with original modeling

Benefits (& Problems) of Lithium Coated PFCs Provide Fertile Ground for Theory & Modeling

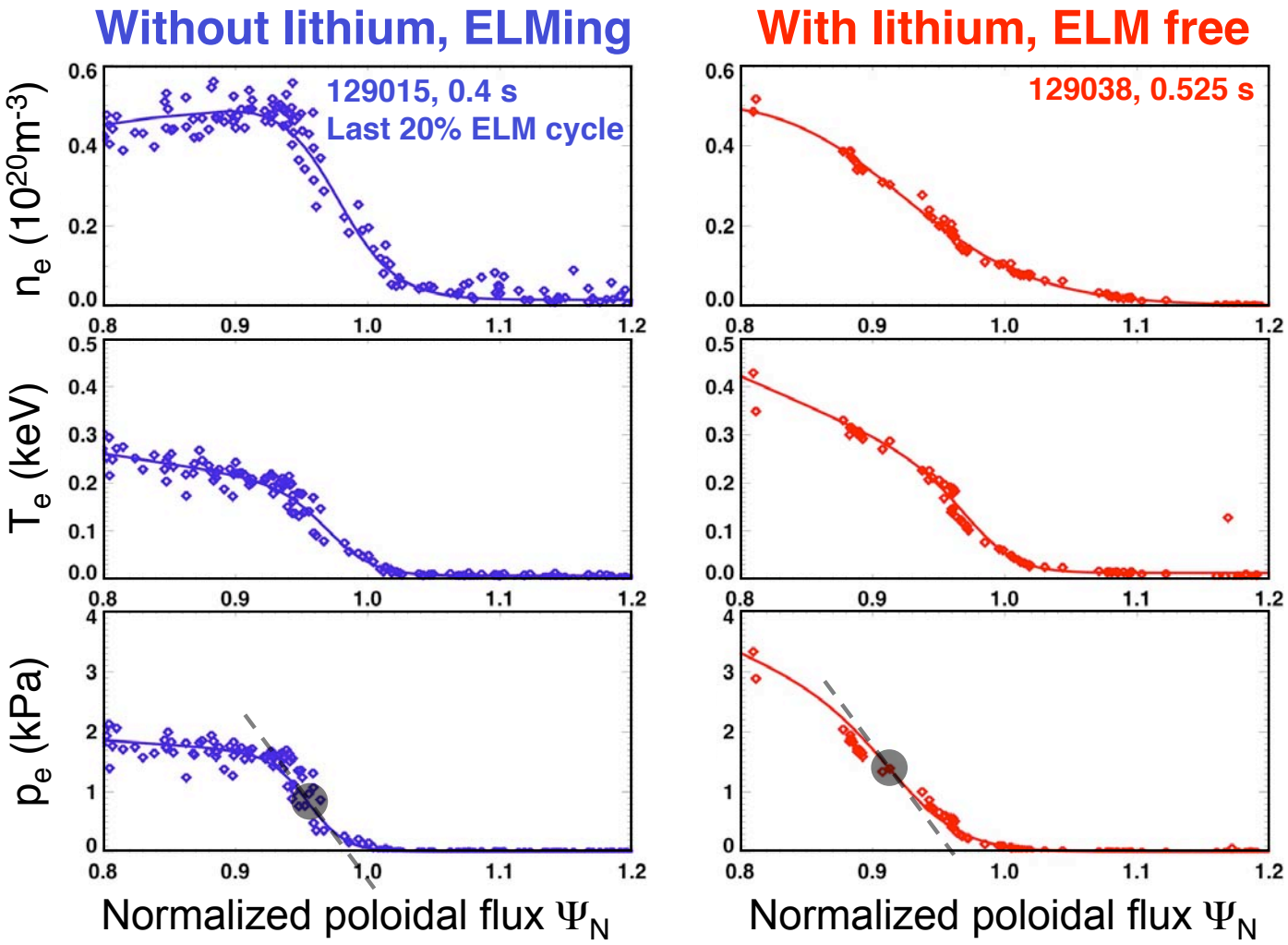
- Reduced hydrogenic recycling
  - Theory and modeling of particle transport including neoclassical and anomalous transport
  - How are edge flows changed by the presence of divertor pumping?
- Reduced H-mode threshold power by up to a factor 4
  - Models for edge barrier formation
  - Z-dependence of particle transport and role in impurity accumulation
- Improved confinement, particularly in electron channel
  - Roles of high- and low- k turbulence & suppression at low aspect ratio
- ELM suppression through changes in edge profiles
  - Is peeling-ballooning model adequate and extrapolable?
  - Roles of edge currents and flows and how these are changed
  - Extrapolable models for ELM triggering by magnetic perturbations
- Optimizing ICRH coupling to core plasma
  - Role of parasitic surface waves and loss processes
- We already have a wealth of data on lithium effects but *guidance on new diagnostics or upgrades to address critical theory needs is encouraged*

Supplementary material on

ELM Effects of Lithium

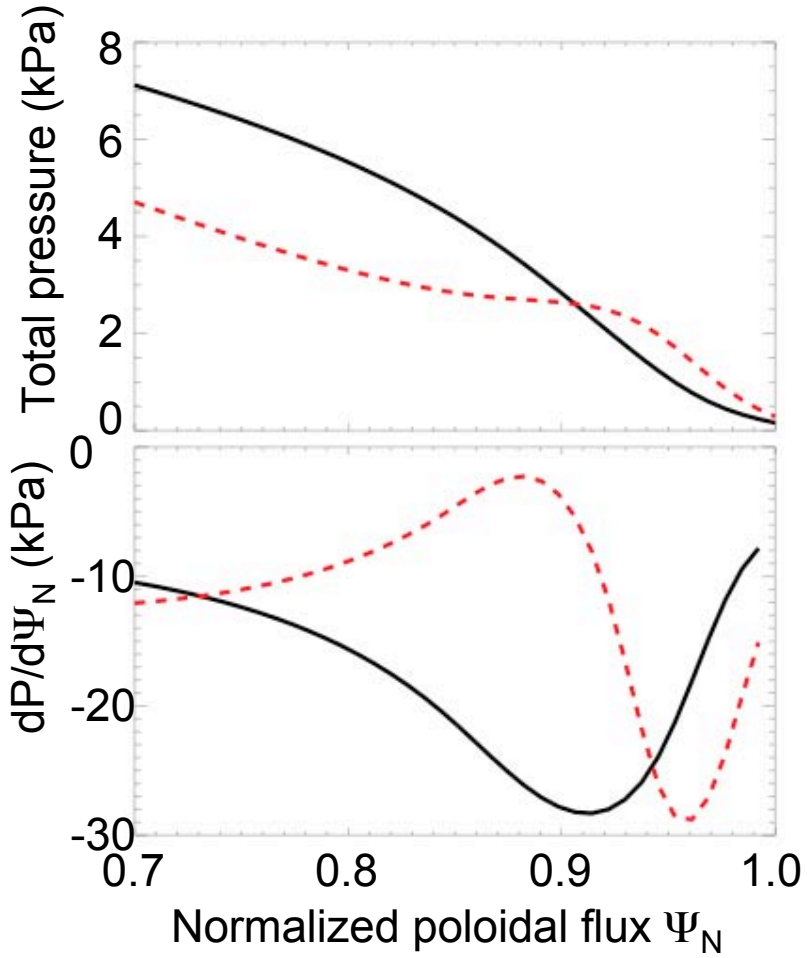
Lithium Affects ELMs Through Changes in Temperature and Pressure Profile at Edge

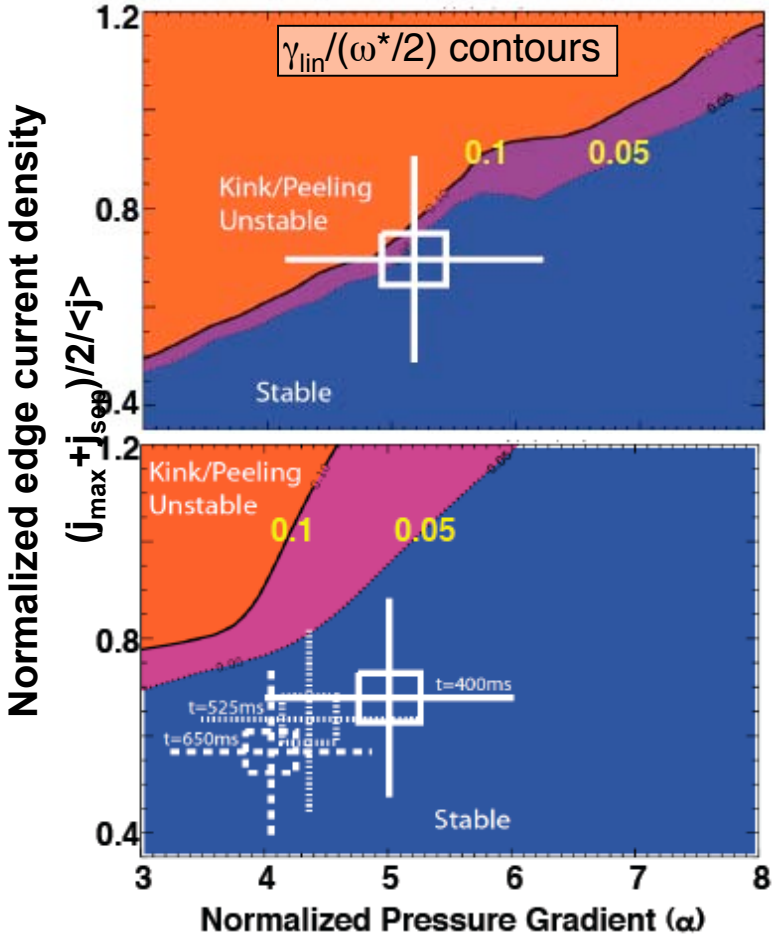
- Multiple timeslices mapped into composite profiles using EFIT equilibrium



Shift of Maximum in ∇p_e to Region of Lower Shear with Lithium Stabilizes Kink/Ballooning

- Analysis with PEST and ELITE codes
- Change in recycling affects edge current
- Precursor activity with n = 1 – 5 observed before ELM onset





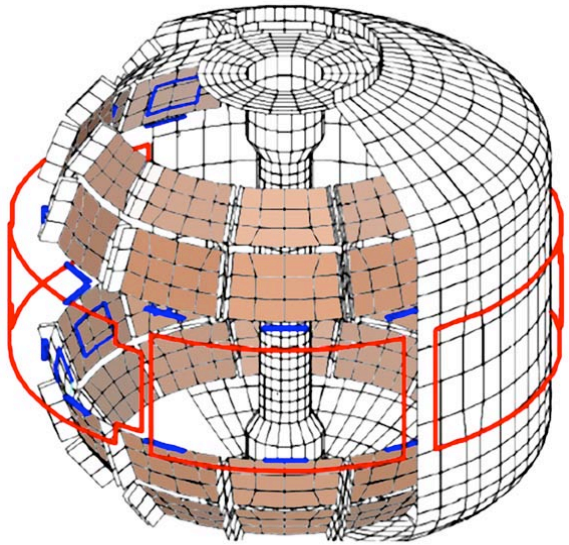
Without lithium (end of ELM cycle)

With lithium

R. Maingi, T. Osborne [PRL 103 (2009) 075001]

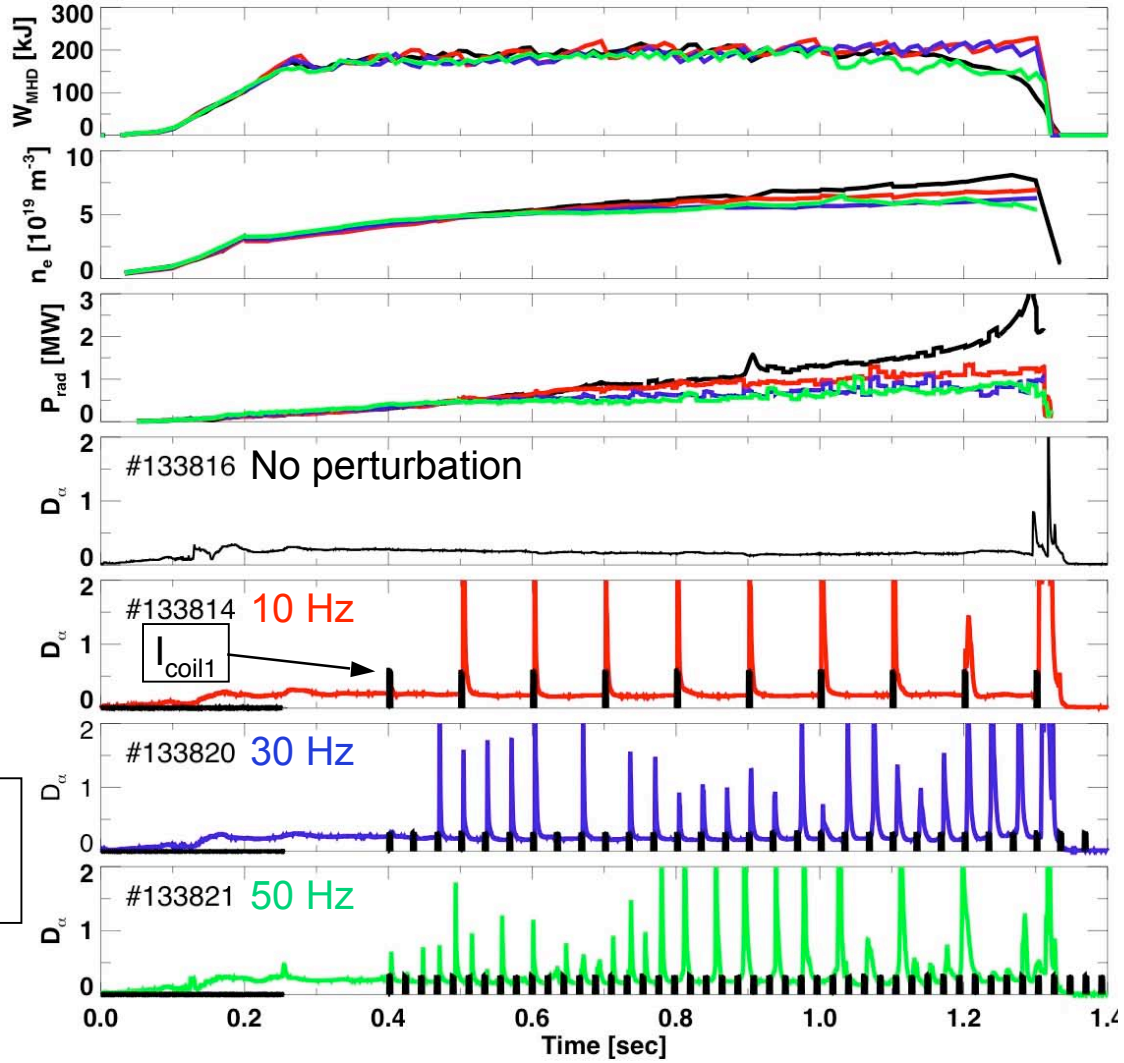
External Non-Axisymmetric Coils Can *Induce* Repetitive ELMs in Discharges with Lithium Coating

Generate n = 3 resonant radial field perturbations with 3 pairs of midplane coils



3 Switching Power Amplifiers applied trains of 3kA, 4ms square pulses

Double-null, κ=2.4, δ=0.8, 0.8MA, 0.45T, NBI 4 MW



- **Induced ELMs reduce n_e, P_{rad}, Z_{eff} with small effect on plasma energy**