NSTX PPPL PRINCETON PLASMA PHYSICS LABORATORY

Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Plasma Response to Lithium-Coated Plasma-Facing Components in NSTX*

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NSTX Team

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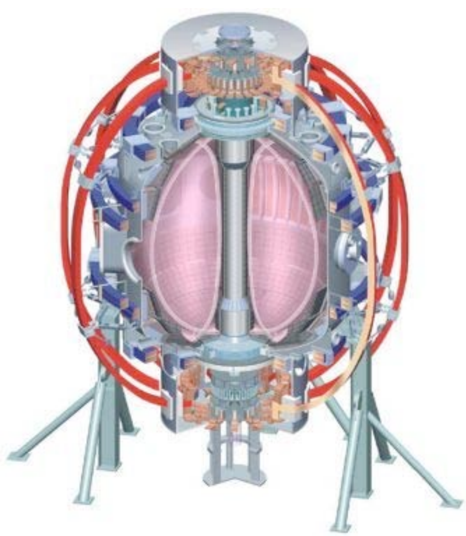

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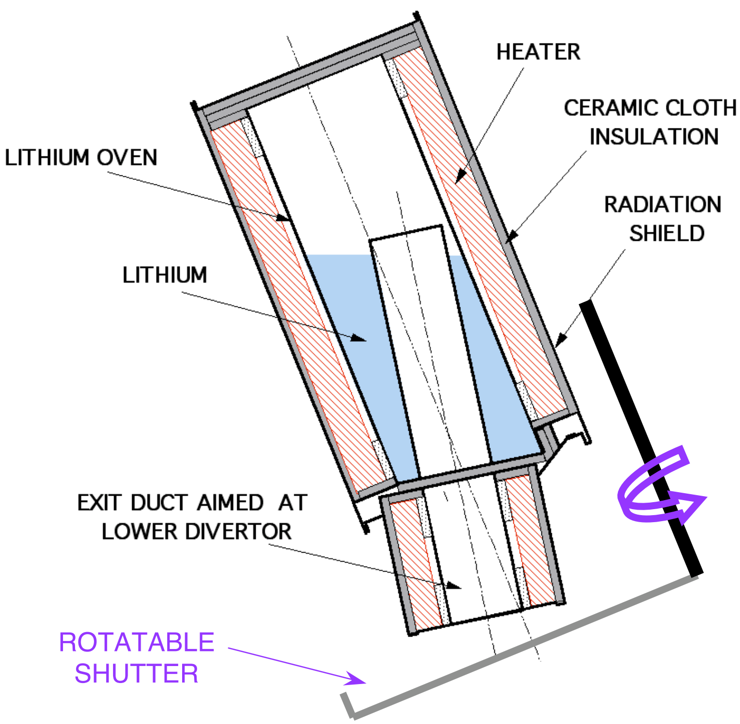
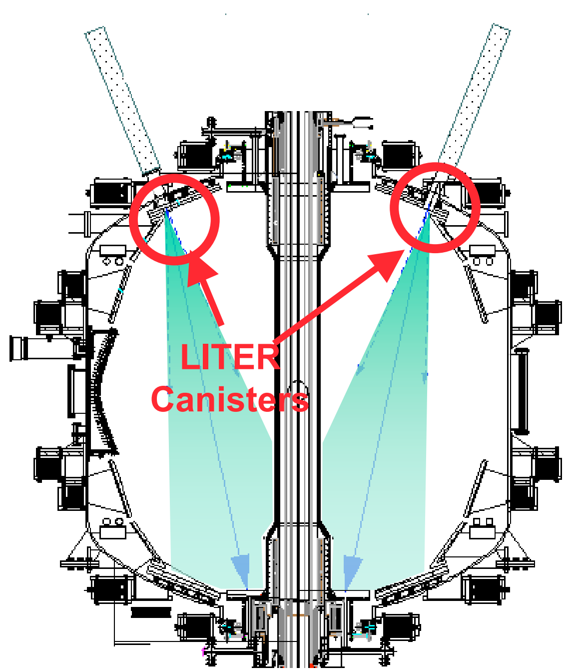
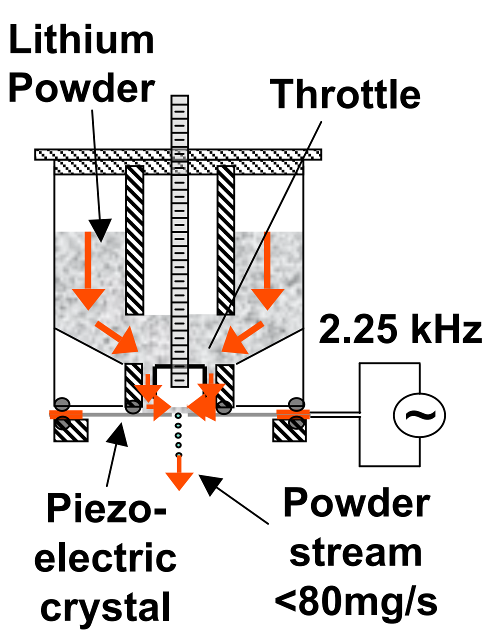
Dual "LITERs" Replenish Lithium Layer on Lower Divertor Between Tokamak Discharges

- Each evaporates 1 – 40 mg/min with lithium reservoir at 520 – 630°C
- Rotatable shutters interrupt lithium deposition during discharges & HeGDC
- Withdrawn behind airlocks for reloading and initial melting of lithium charge
- Reloaded LITERs 6 times during 2009 run (Mar - Aug): ~300g deposited
  - ~80% of plasmas in latter part of 2009 run preceded by lithium evaporation
- Also used a "dropper" to introduce lithium powder into plasma SOL

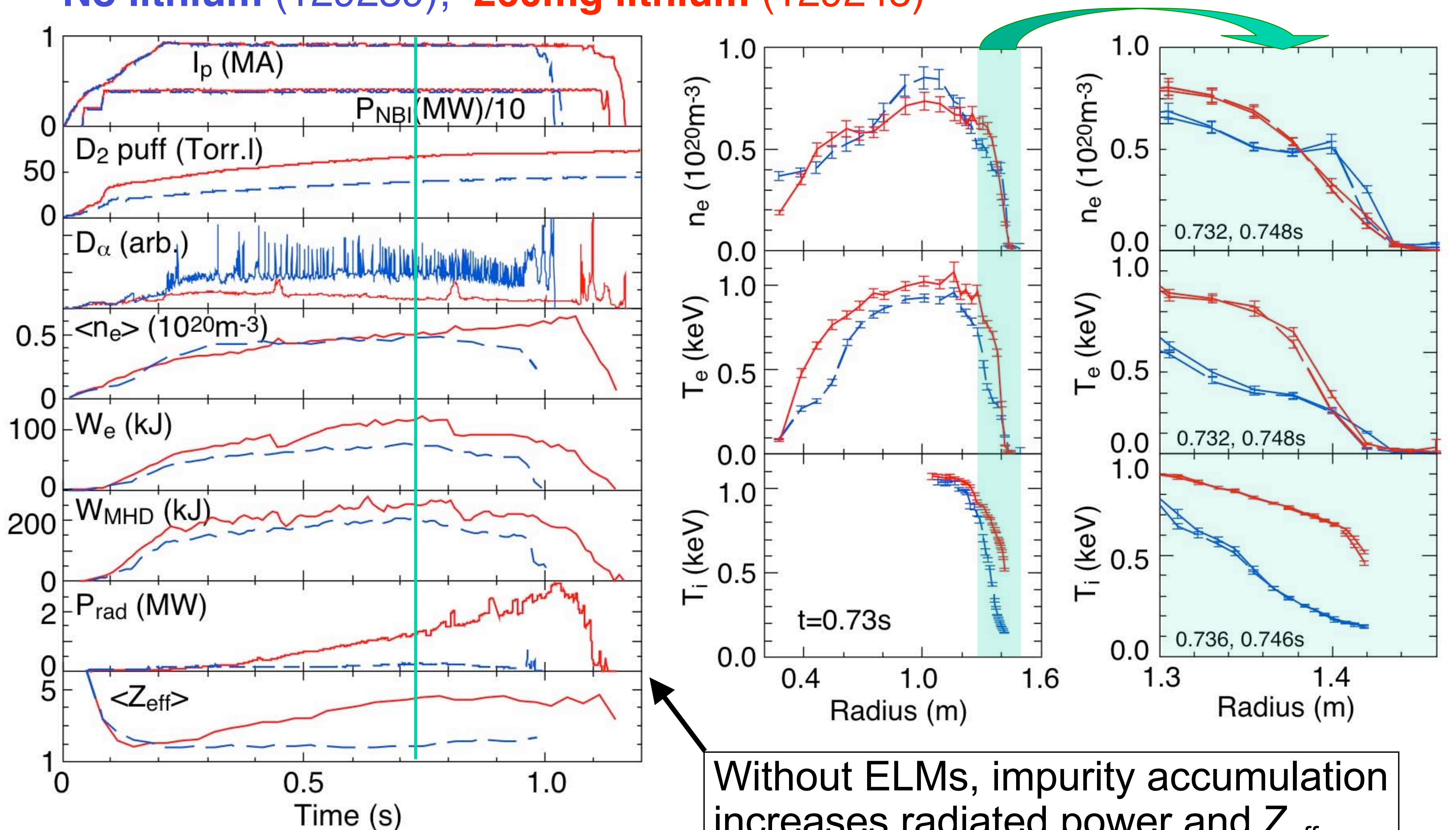






Lithium Coating Reduces Deuterium Recycling, Suppresses ELMs, Improves Confinement

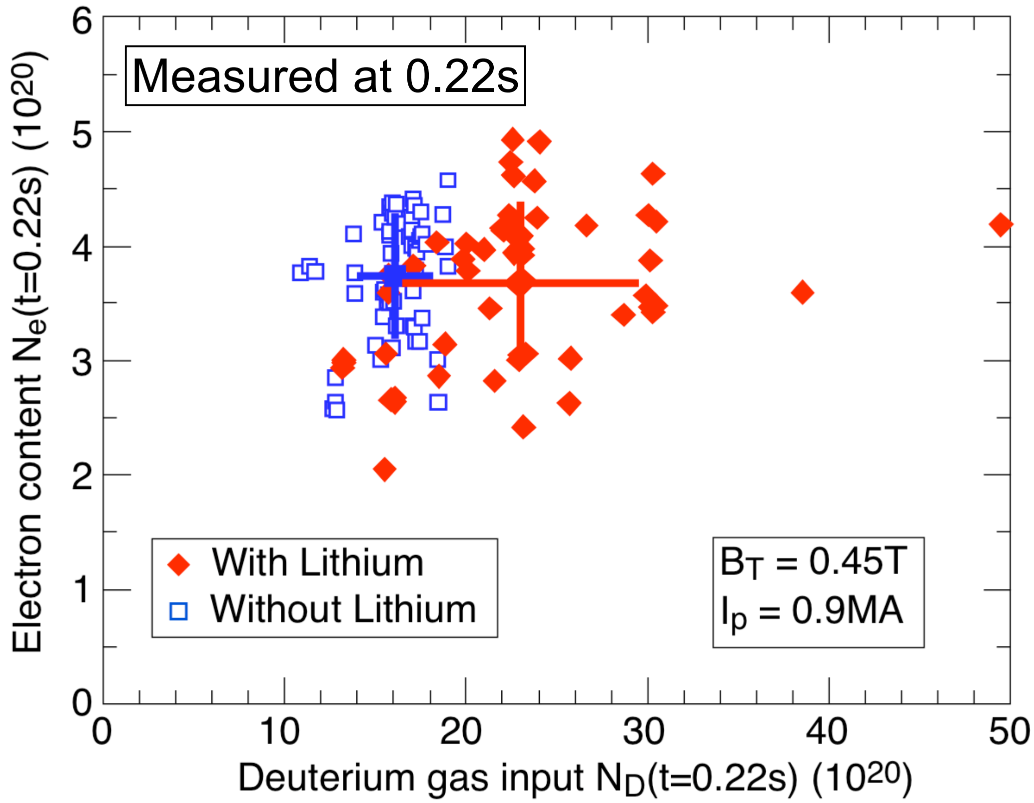
No lithium (129239); **260mg lithium** (129245)



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

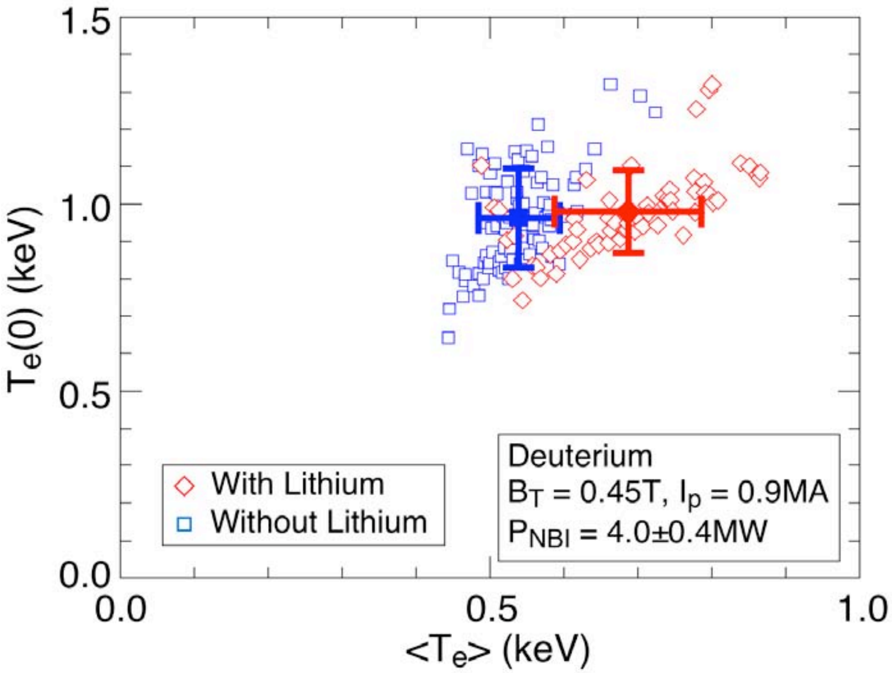
Lithium Reduces Deuterium Recycling but Need to Increase Fueling to Avoid Early Locked Modes

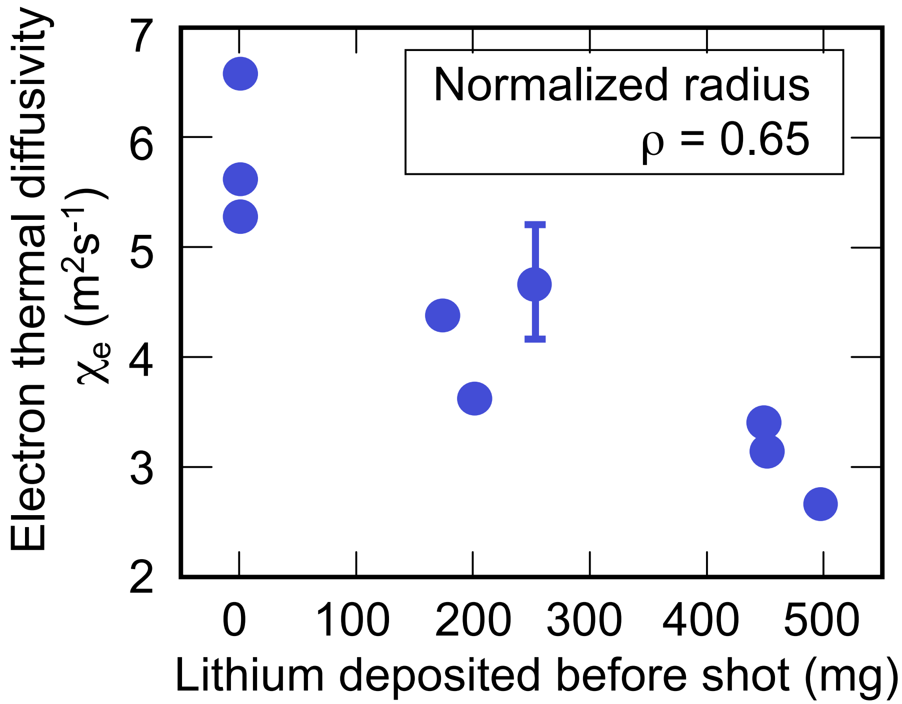
- 1-D tangential camera for edge D_α emission shows greatly reduced neutral D density across outboard midplane with lithium
- Lower density achievable early in discharges both with and without lithium but likelihood of deleterious locked modes increases
  - Extensive HeGDC, He ohmic- or HHFW-heated plasmas also reduce recycling



- H-mode threshold power reduced by factor ~2 by lithium coating

Improvement in Electron Confinement Arises from Broadening of Temperature Profile

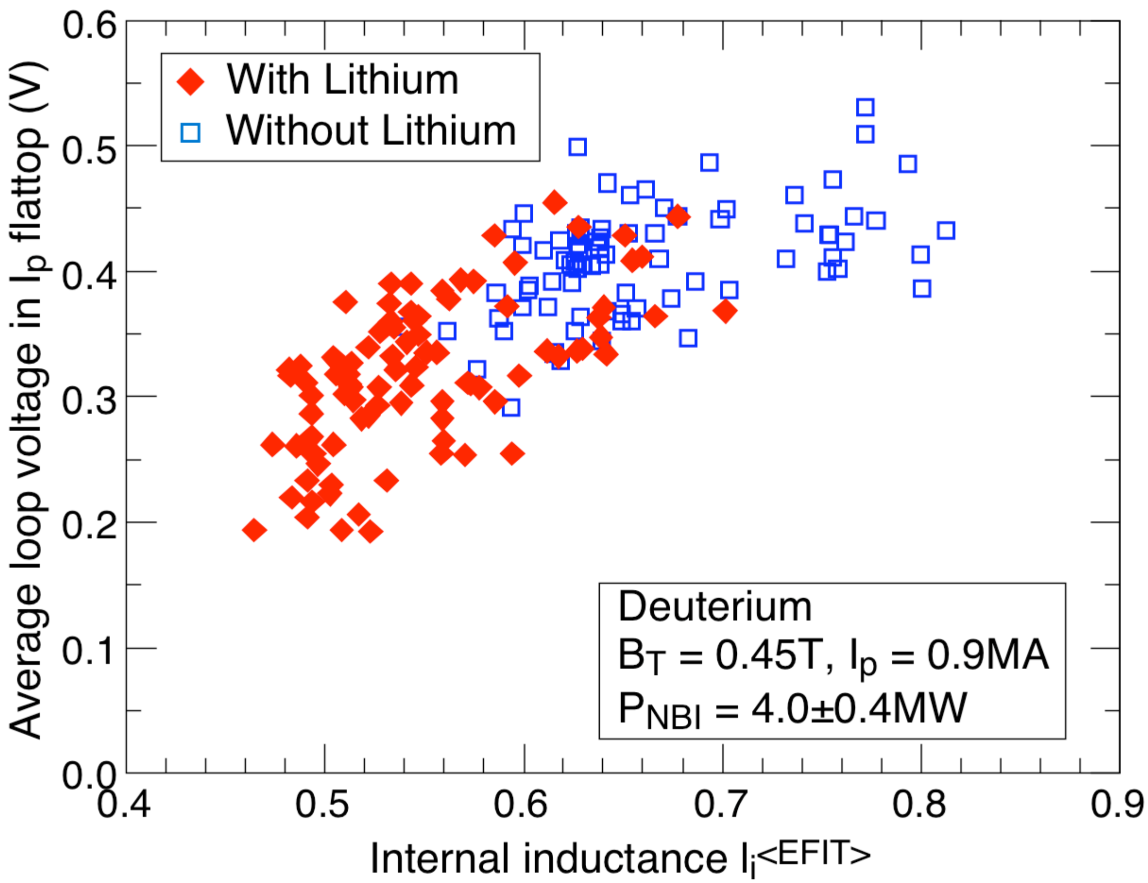




- TRANSP analysis confirms electron thermal transport in outer region progressively reduced by lithium
- Fast-ion contribution to total energy increased
- Thermal ion confinement remains close to neoclassical level both with and without lithium

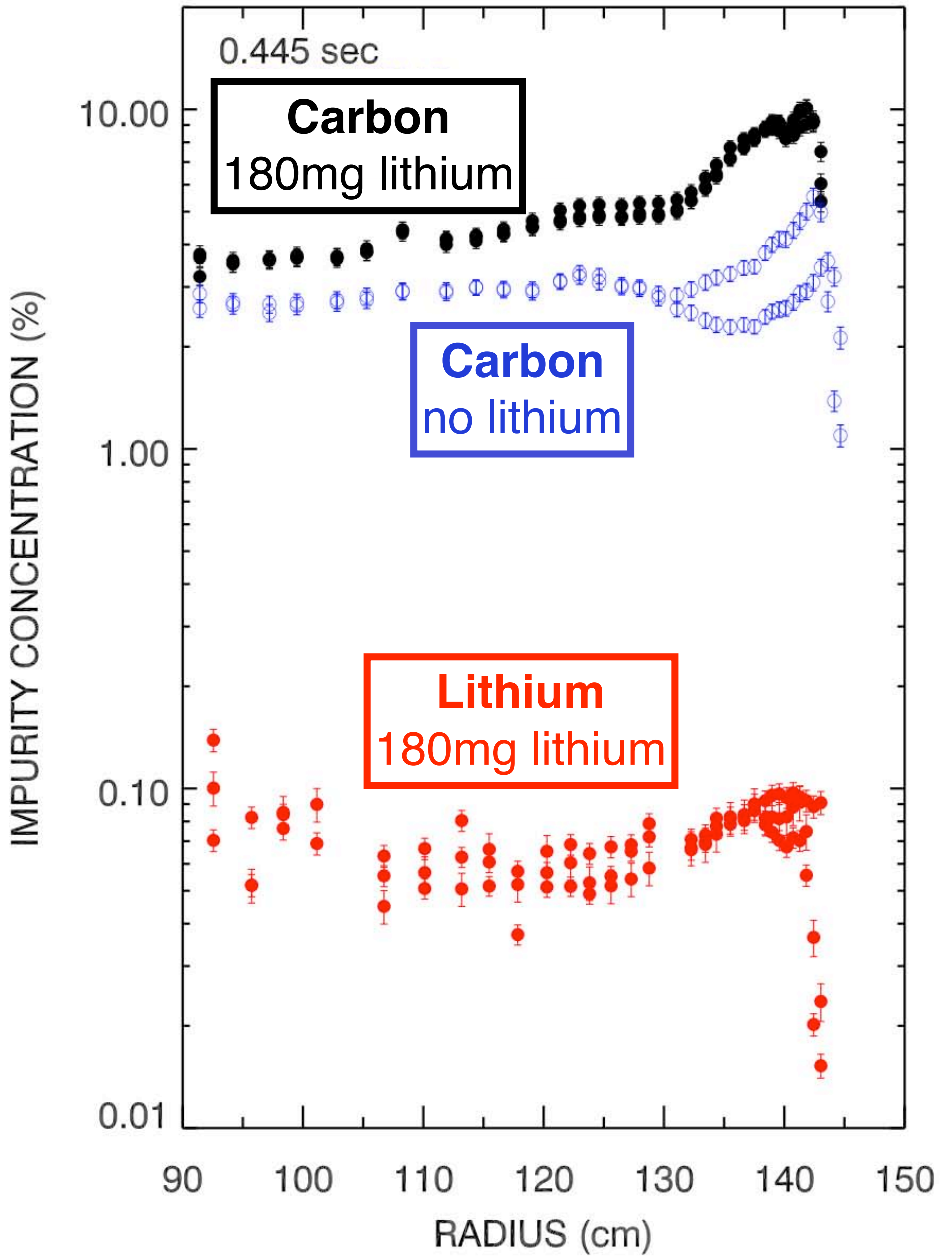
Broader T_e Profile with Lithium Coating Reduces Both Inductive and Resistive Flux Consumption

- Bootstrap current fraction also increases
- Critical issue for development of low-aspect ratio tokamaks

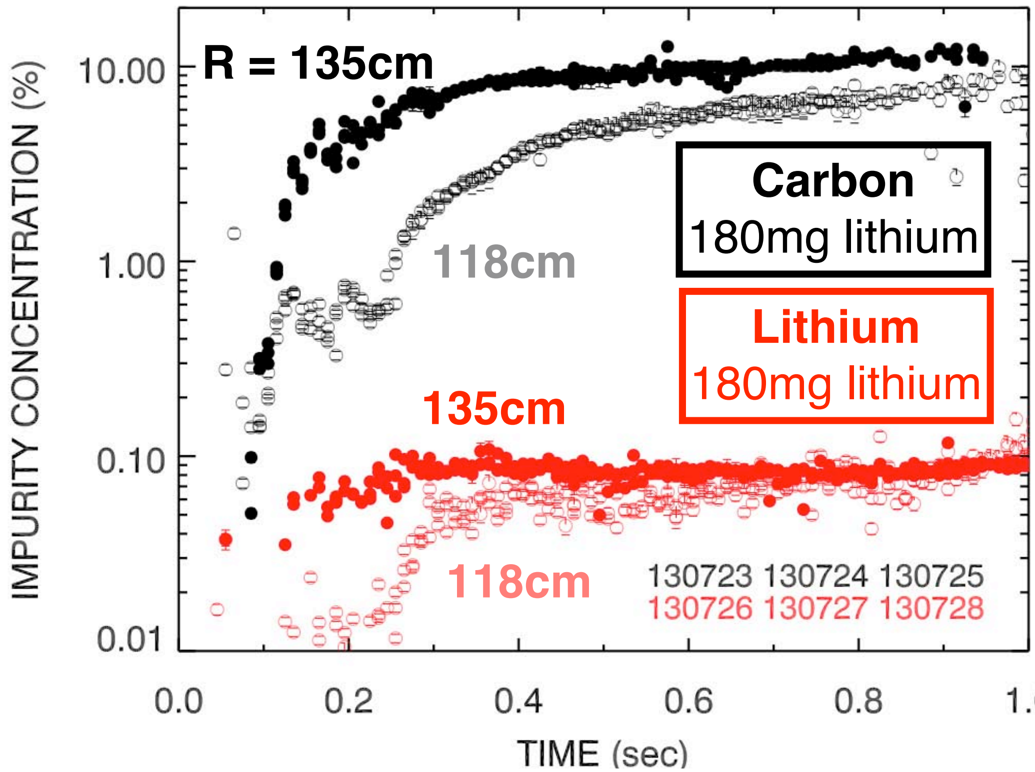


- Reduction occurs despite increase in $\langle Z_{eff} \rangle$ in ELM-free H-modes after lithium coating

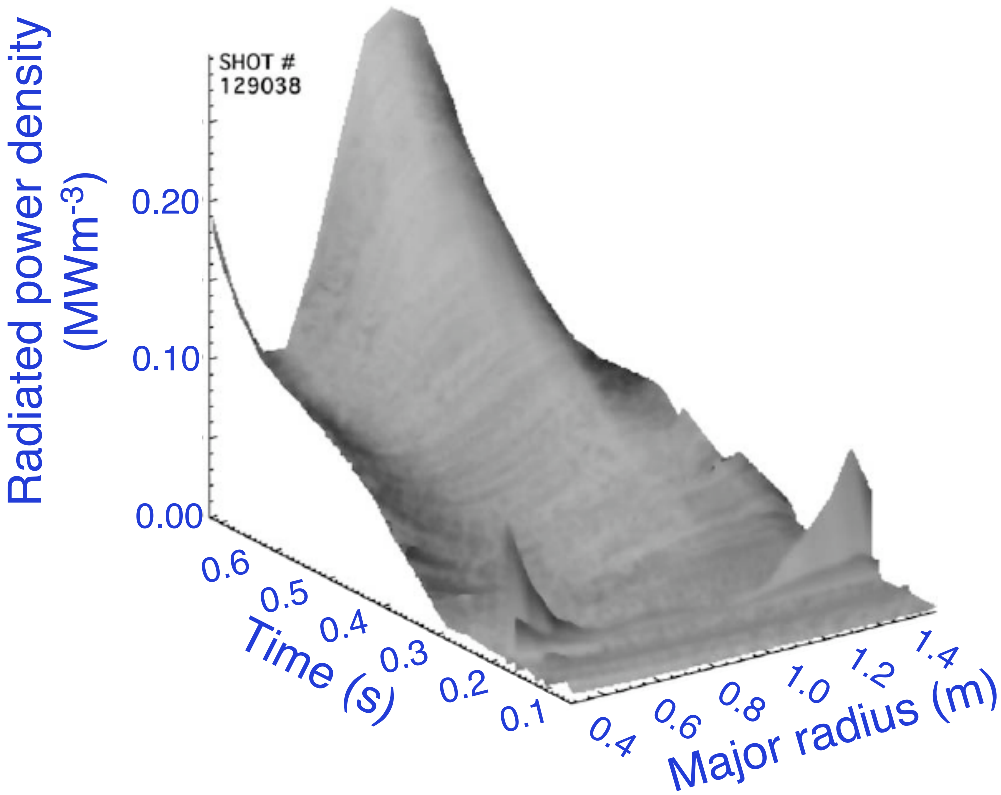
Lithium Concentration in Plasmas Remains Low but Carbon Concentration Rises with Lithium Coating

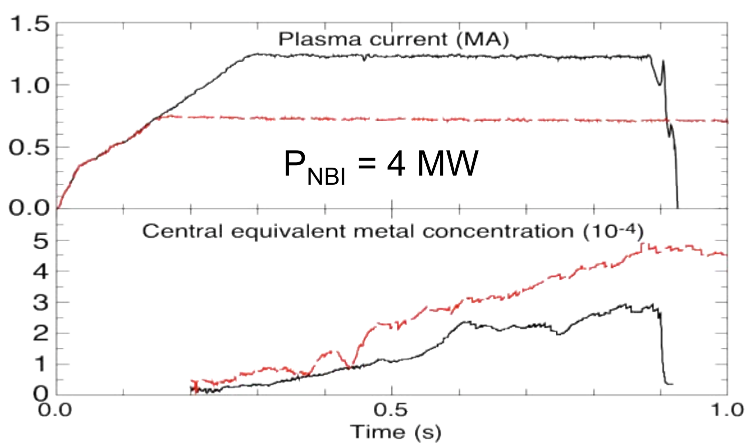


- Quantitative measurements of C^{6+}, Li^{3+} with charge-exchange recombination spectroscopy
- **n_C/n_{Li} ~ 100**
- Hollow profiles early for both C and Li fill in as time progresses



Metals Responsible for Most of the Increase in Radiation When ELMs Suppressed by Lithium

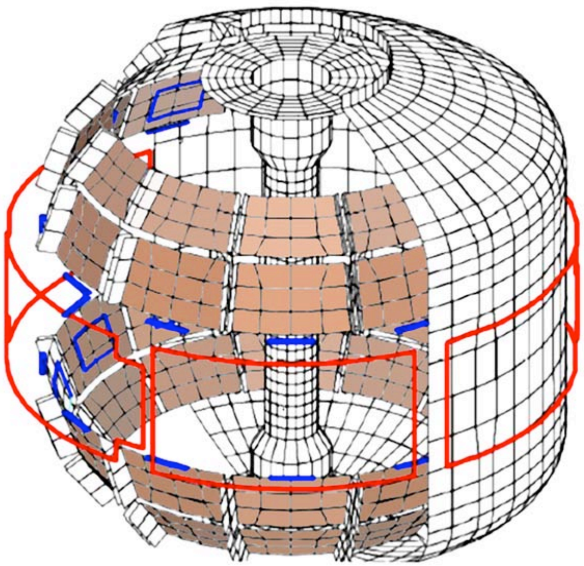




- Radiated power centrally peaked in ELM-free discharges
- VUV and SXR spectra show iron lines (Fe X – XVIII) increasing during ELM-free periods
- Radiated power profile remains hollow when ELMs are present
  - Metals still present early but do not accumulate
- If increase in radiation is ascribed to iron-like metals:
  - $n_{\text{"Fe"}}/n_e \sim 0.1\%$
  - ΔZ_{eff}("Fe") ~ 0.3
- Dependence of rate of rise of radiation on I_p suggests sputtering by unconfined NB ions is source

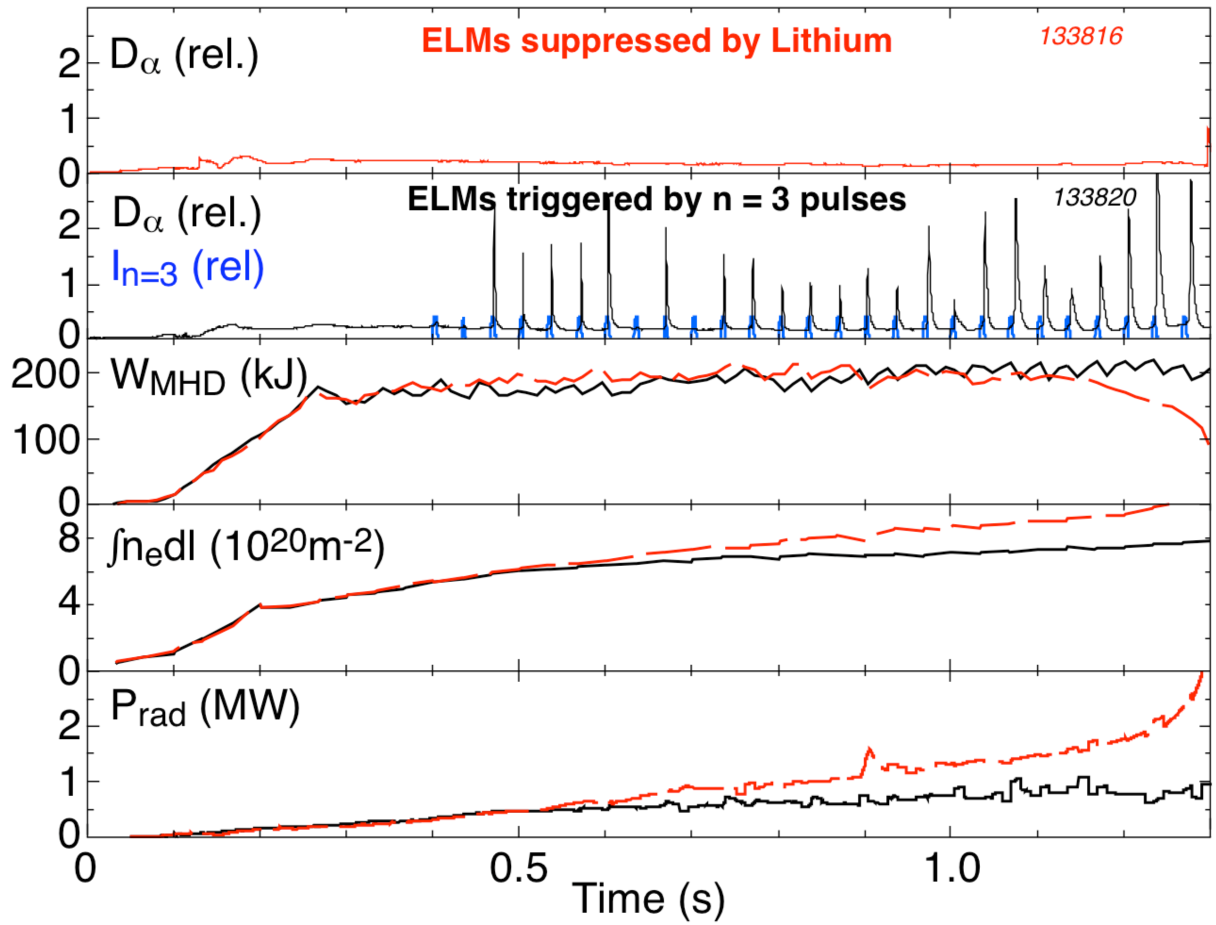
External Non-Axisymmetric Coils Can *Induce* Repetitive ELMs in Discharges with Lithium Coating

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**

Lithium Coating of Carbon PFCs Has Shown Benefits for Divertor Plasma Operation in NSTX

- Improves discharge reproducibility
- Reduces hydrogenic recycling
  - Eliminates need for helium glow-discharge cleaning between shots
- Reduces H-mode threshold power by factor 2
- Improves confinement
  - Electron confinement increased up to 40%
- Enables longer pulse lengths
  - Broader T_e reduces both inductive and resistive flux consumption
  - Active error field correction and mode control suppress MHD instability
- Suppresses ELMs in H-mode plasmas
  - ELM suppression increases carbon and high-Z metallic impurities
  - Lithium concentration remains very low
  - Metals responsible for secular rise in central radiation
  - Can trigger ELMs with external coils to reduce deleterious effects of impurities with small impact on confinement

Other Lithium-Related Presentations

JO4.5	A.C. Sontag *et al.*	Discharge Evolution Control via 3D Field ELM Pacing in NSTX
JO4.8	C.H. Skinner *et al.*	Deuterium retention in NSTX with lithium conditioning

Poster session PP8, Wednesday November 4, 2:00pm *Grand Hall East*

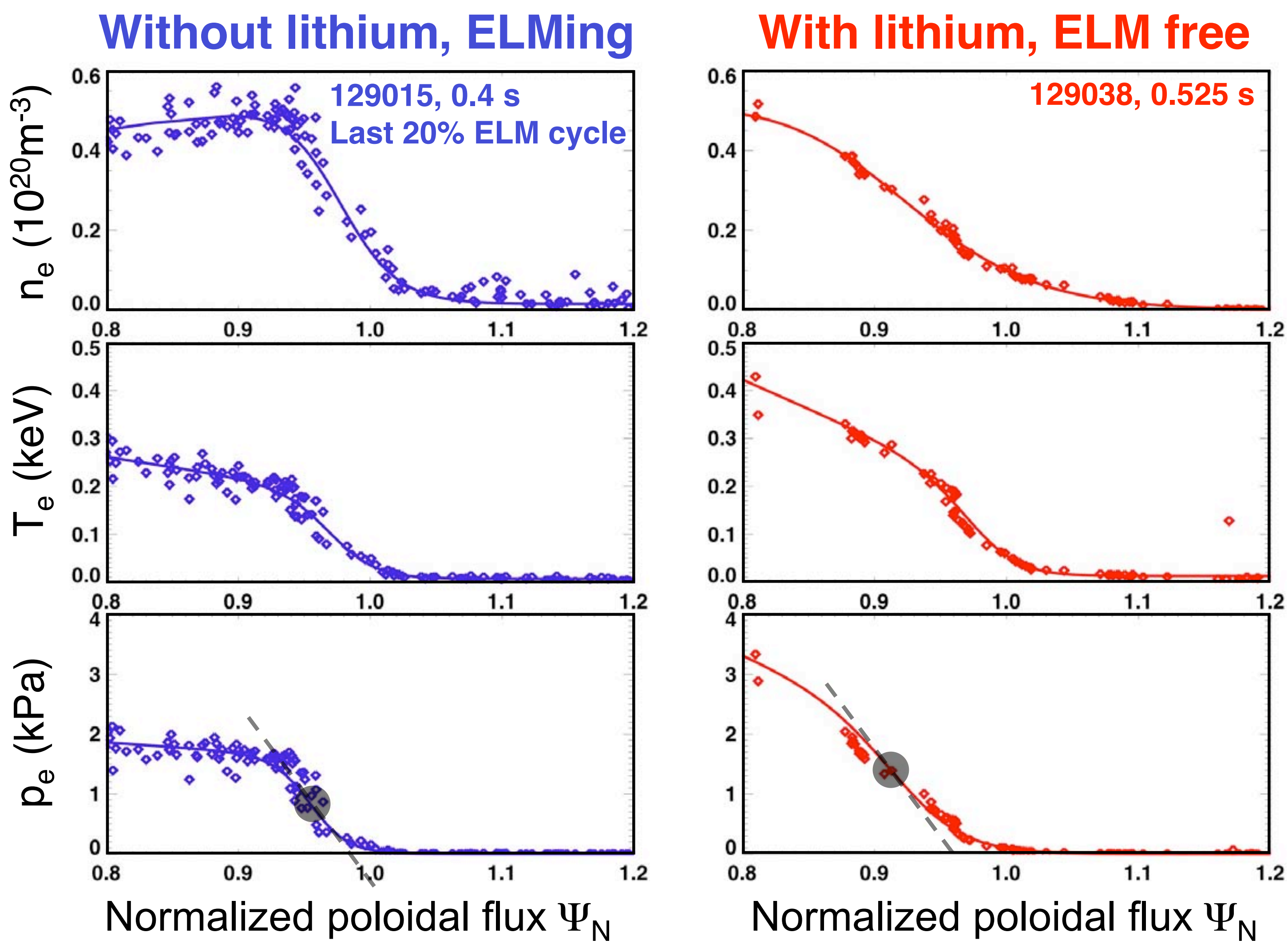
PP8.36	D.K. Mansfield *et al.*	Continuation of Lithium Aerosol Injection Experiments on NSTX
PP8.37	V. Soukhanovskii *et al.*	Modifications in divertor and scrape-off layer conditions with lithium coatings in NSTX
PP8.38	S. Paul *et al.*	Dependence of impurity accumulation on Ip and the outer gap in the presence of lithium deposition in NSTX
PP8.39	J.K. Lepson *et al.*	Identification and time evolution of impurities in NSTX plasmas
PP8.40	C.N. Taylor *et al.*	Time dependent chemical interactions of lithium, deuterium, and oxygen on lithium-coated graphite surfaces
PP8.41	R.D. Smirnov *et al.*	Modeling of low-recycling divertor with lithium coating in NSTX
PP8.42	F. Scotti *et al.*	Modeling of Balmer series deuterium spectra with the Cretin code for diagnosing the inner divertor re-attachment threshold in NSTX discharges with lithium coatings
PP8.47	S. Ding *et al.*	Characteristics of energy transport of Li- and non-Li-conditioned plasmas in NSTX

Posters on the NSTX Liquid Lithium Divertor

PP8.44	H.W. Kugel *et al.*	Status of National Spherical Torus Experiment Liquid Lithium Divertor
PP8.45	J. Kallman *et al.*	Development of Operational Scenarios and Edge Diagnostics for the NSTX Liquid Lithium Divertor
PP8.46	R. Kaita *et al.*	Diagnostics for Evaluating Performance of NSTX Liquid Lithium Divertor

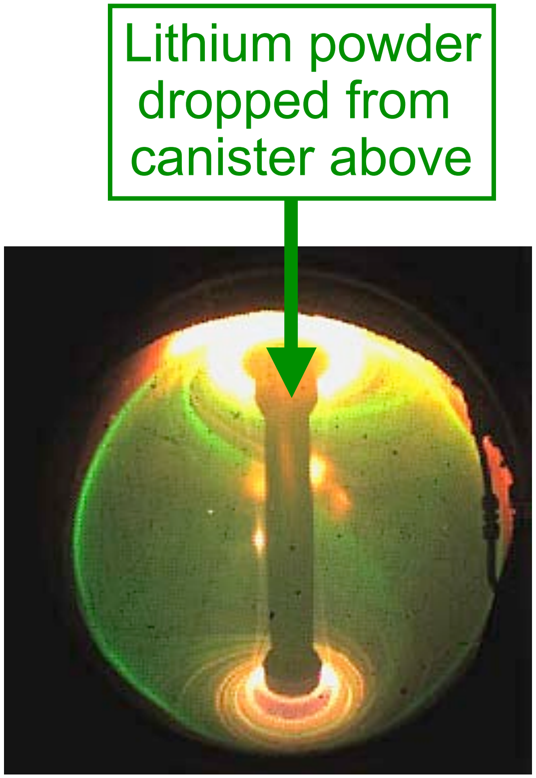
Lithium Affects ELMs Through Changes in Temperature and Pressure Profile at Edge

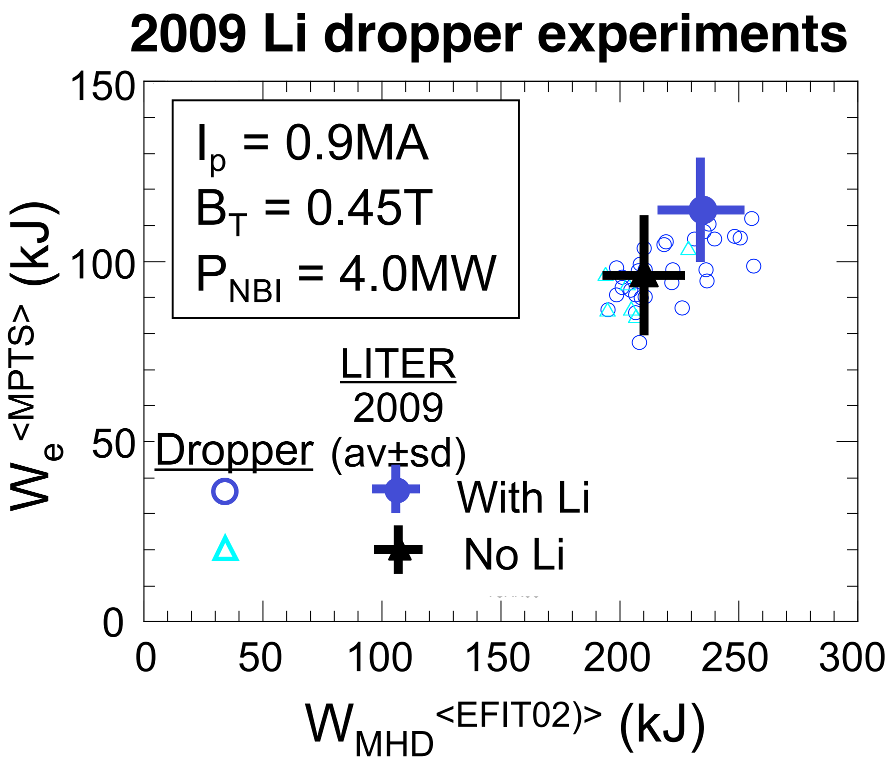
- Multiple timeslices mapped into composite profiles using EFIT equilibrium



Also Investigated Lithium Coating by Dropping a Stream of Lithium Powder into SOL

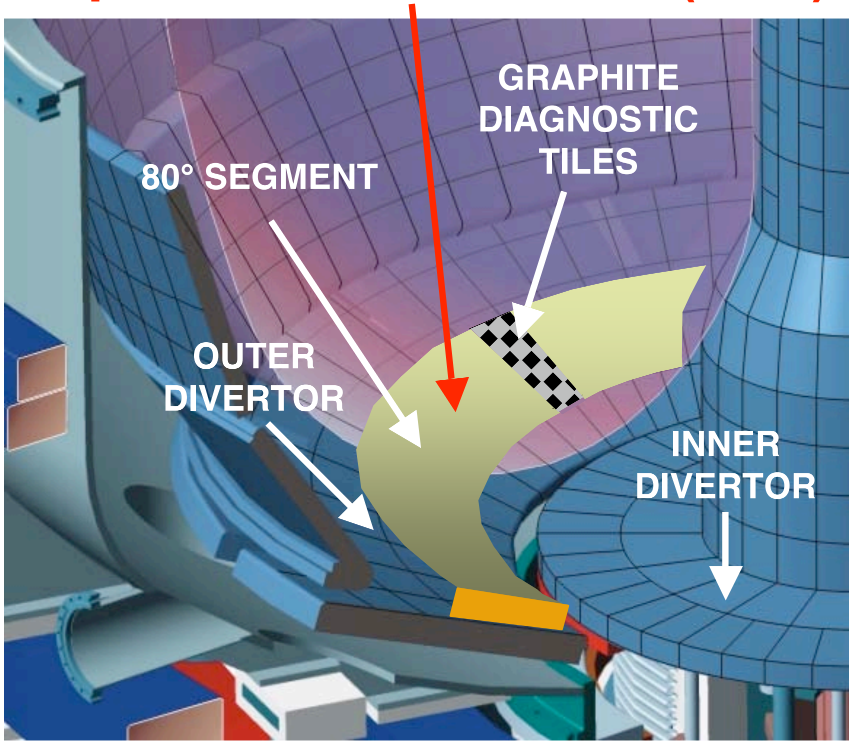
- Lithium powder (~40μm) introduced by oscillating a piezo-electric diaphragm with a hole in the center on which the powder is piled
- Typical flow rates 5 – 80 mg/s: ***well tolerated by plasma, even in startup***
- In initial 2008 experiment, improved confinement, reduced flux consumption
- In 2009, 50 – 100 mg powder injected, but improvement less reliable





In 2010, NSTX Will Begin Investigating Liquid Lithium on Plasma Facing Components

Liquid Lithium Divertor (LLD)



- Replace rows of graphite tiles in outer lower divertor with 4 segmented plates
- Semi-porous (~50%) plasma-sprayed molybdenum surface (~150µm) on copper plate with temperature control
  - Capability to heat to >400C (Li melting point 180°C)
- Initially supply lithium with LITERs and possibly lithium powder dropper

- Evaluate capability of liquid lithium to sustain deuterium pumping in high-power tokamak environment
  - Laboratory measurements in PISCES and experience in CDX-U show that liquid has much higher capacity for deuterium retention than solid