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NSTX

Plasma Performance Improvement with Lithium-Coated Plasma-Facing Components in NSTX*

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Abstract

Lithium as a plasma-facing material has many attractive features, including a reduction in the recycling of hydrogenic species and the potential for withstanding high heat and neutron fluxes in fusion reactors. Recent NSTX experiments have shown, for the first time, significant and recurring benefits of lithium coatings on plasma-facing components (PFC's) to the performance of divertor plasmas in both L- and H- mode confinement regimes heated by high-power neutral beams. They included decreases in the plasma density and inductive flux consumption, and increases in the electron temperature, ion temperature, energy confinement time, and DD neutron rate. Extended periods of MHD quiescence were also achieved, and measurements of the visible emission from the lower divertor showed a reduction in the deuterium, carbon, and oxygen line emission. Other salient results with lithium evaporation included a broadening of the electron temperature profile, and changes in edge density gradients that benefited electron Bernstein wave coupling. There was also a reduction in ELM frequency and amplitude, followed by a period of complete ELM suppression. In general, it was observed that both the best and the average confinement occurred after lithium deposition and that the increase in W_{MHD} occurs mostly through an increase in W_e. In addition, a liquid lithium divertor (LLD) is being installed on NSTX this year. As the first fully-toroidal liquid metal divertor target, experiments with the LLD can provide insight into the behavior of metallic ITER PFC's should they liquefy during high-power divertor tokamak operations. The NSTX lithium coating and LLD experiments are important near-term steps in demonstrating the potential of liquid lithium as a solution to the first-wall problem for both magnetic and inertial fusion reactors.

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Overview

- **Lithium-coatings on plasma-facing components (PFCs) have improved plasma performance on NSTX by:**

  1. **Reducing plasma density in early phase of discharge**
  2. **Suppressing of ELMs**
  3. **Improving energy confinement**
  4. **Reducing flux consumption**
  5. **Increasing pulse length**
  6. **Increasing pedestal electron and ion temperature**
  7. **Reducing SOL plasma density**

Introduction

- Lithium has promise as plasma-facing component (PFC) for fusion reactors

  - Reduces recycling of hydrogenic species

  - Mitigates effects of high heat and neutron fluxes if used as flowing liquid

- Dramatic effects on plasma performance demonstrated on several devices

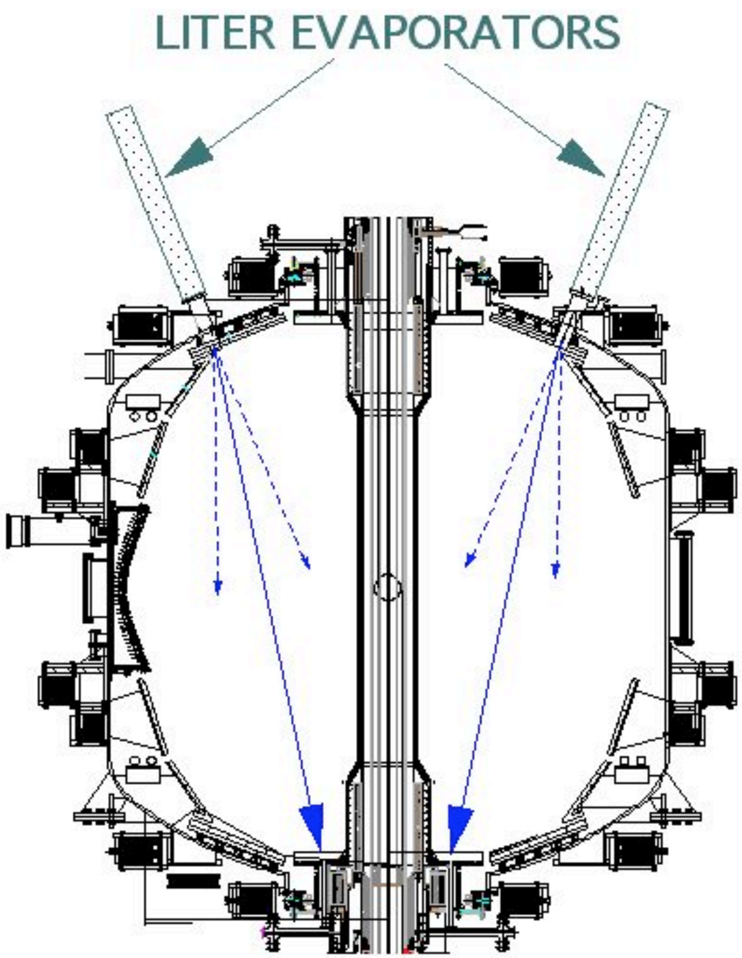
  - Lithium-coated PFC’s used in TFTR, T-11M, and FT-U

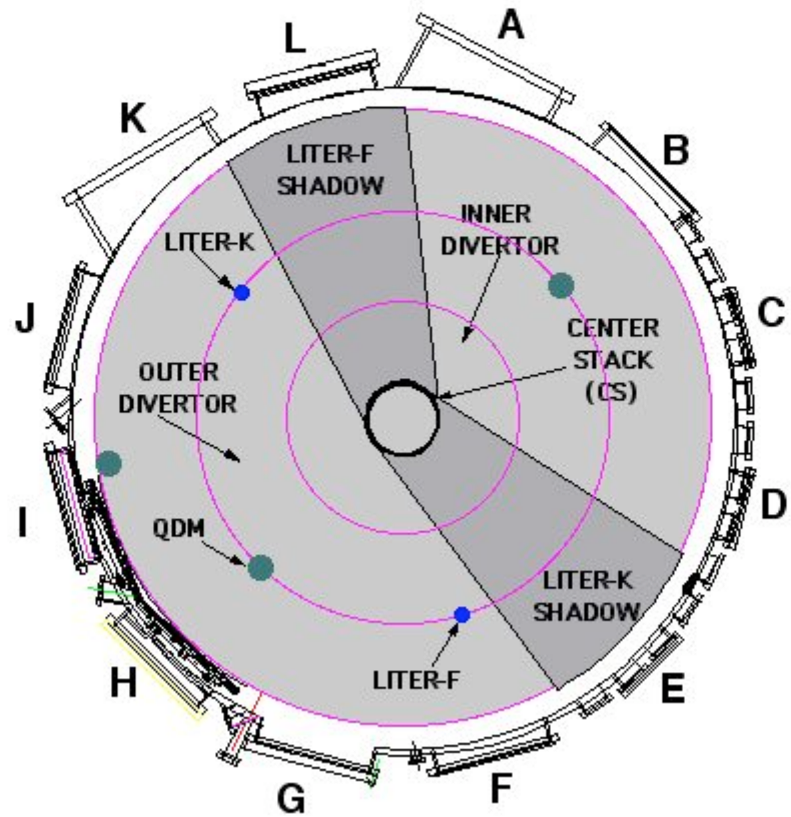
  - Record confinement time enhancement in ohmic plasmas achieved with liquid lithium limiter in CDX-U

- Recent NSTX experiments have shown significant and recurring benefits of lithium coatings on carbon PFC’s

  - First demonstration of performance improvement in both L-mode and H-mode divertor plasmas with neutral beam heating

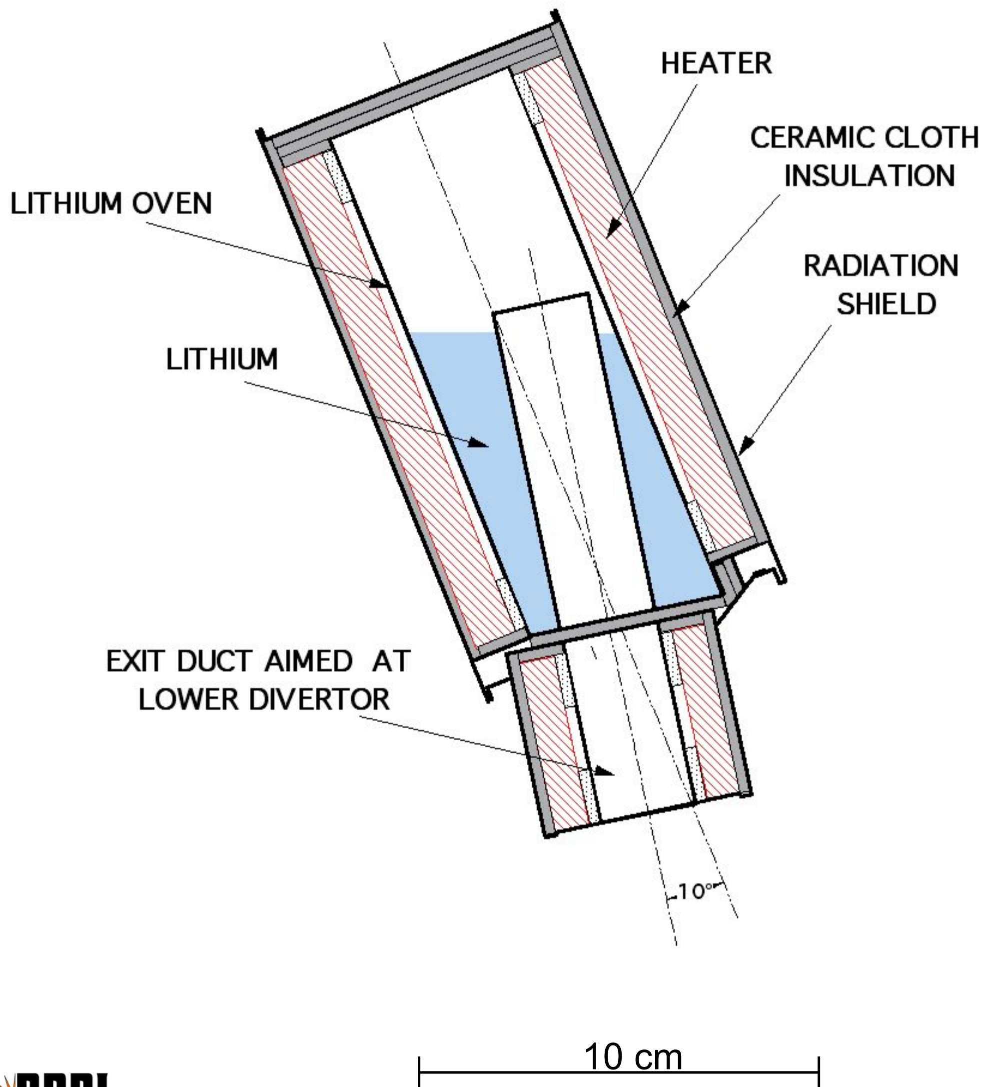
Two LIThium Evaporators (LITERs) oriented for coating NSTX divertor region with lithium





- LITER central aiming axis to graphite divertor and gaussian angle at 1/e (dashed)
- Toroidal locations of LITER and Quartz Deposition Monitors (QDM)

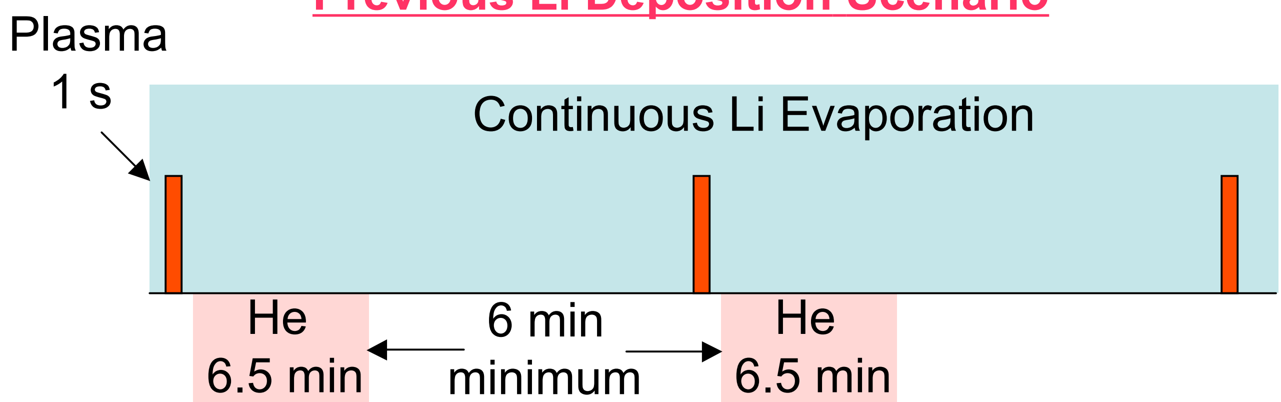
Each LITER consists of lithium reservoir inside heated stainless steel oven



- **LITER on probe & loaded with Li under argon**
- **Typical Operating Conditions**
  - **Capacity: 90 g Li**
  - **Oven Temp: 600-680°C**
  - **Rate: 1mg/min - 80mg/min**

Newly-installed shutter in front of LITER exit allows rapid interruption of PFC coating without cooling lithium oven

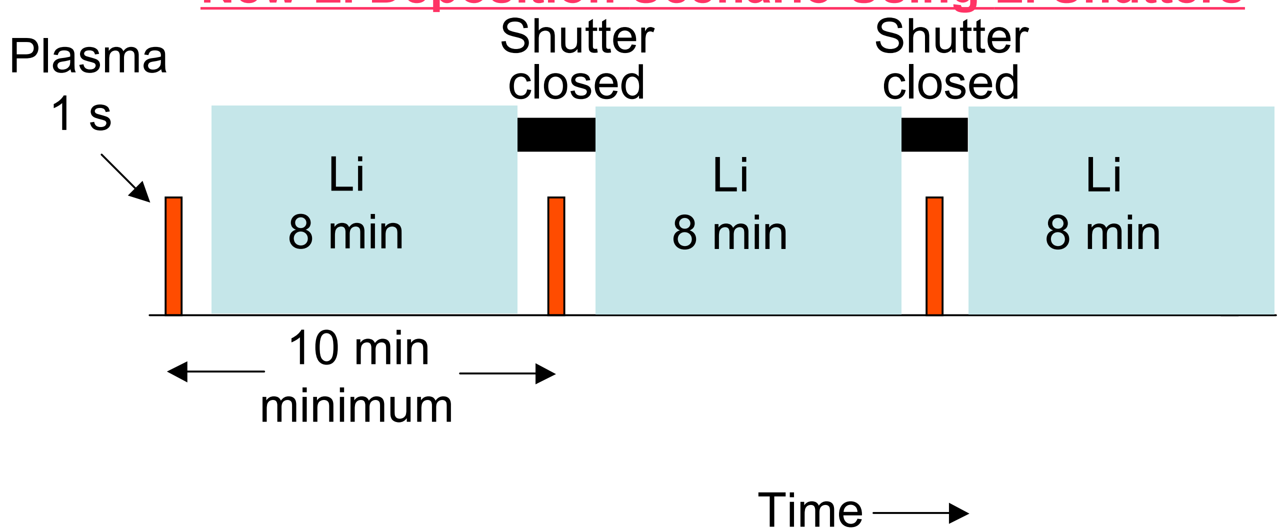
Previous Li Deposition Scenario



Disadvantages

- Window coating during discharge
- Codeposition of Li and He during HeGDC
  - Causes He dilution of D plasma

New Li Deposition Scenario Using Li Shutters

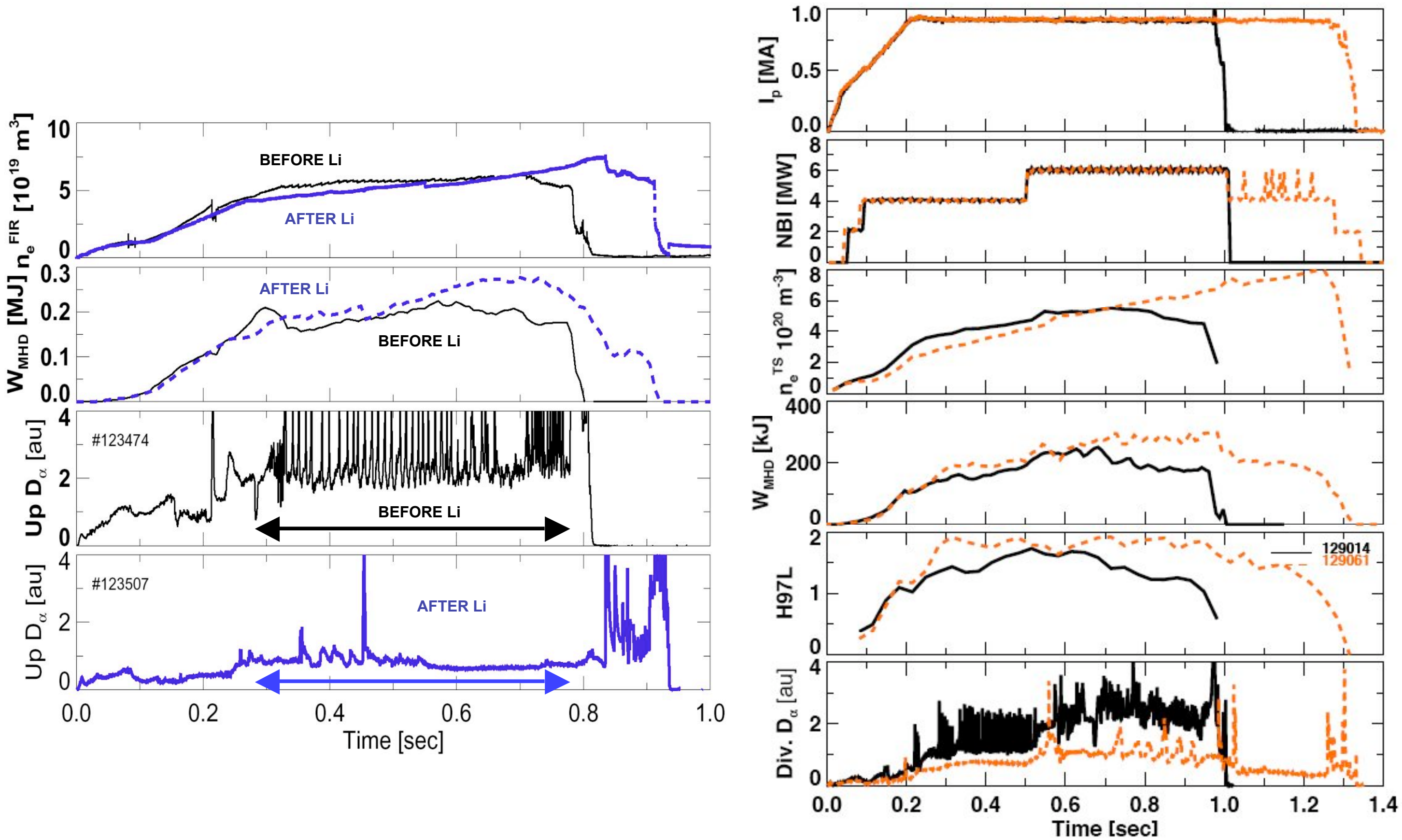


Advantages

- No window coating during discharge
- Allows elimination of HeGDC
  - Reduces time between pulses

Increase in pulse length and ELM suppression achieved with lithium evaporation

(a)

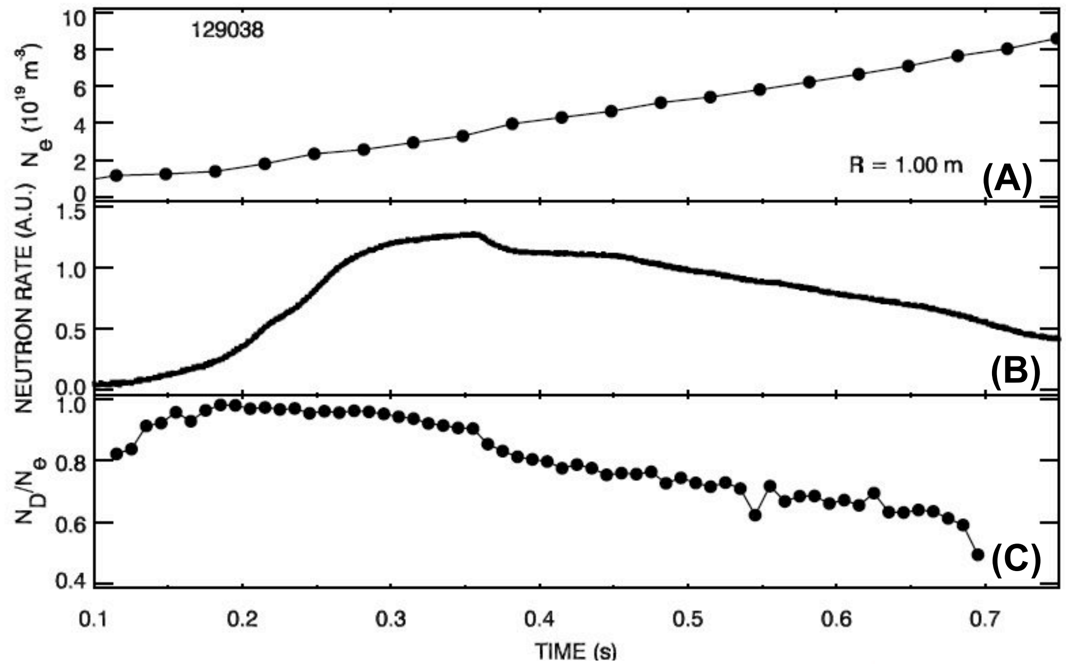


(b)

- Comparison for pre-Li and post-Li plasmas with (a) lower evaporation rate using one LITER prior to 2008 and (b) higher evaporation rate using two LITERs
  - Maximum deposition rate increased from ~40 mg/min to ~80 mg/min with second LITER
  - Addition of improved error-field correction at high beta led to record plasma durations

Lithium PFC coatings affect time evolution of plasma parameters

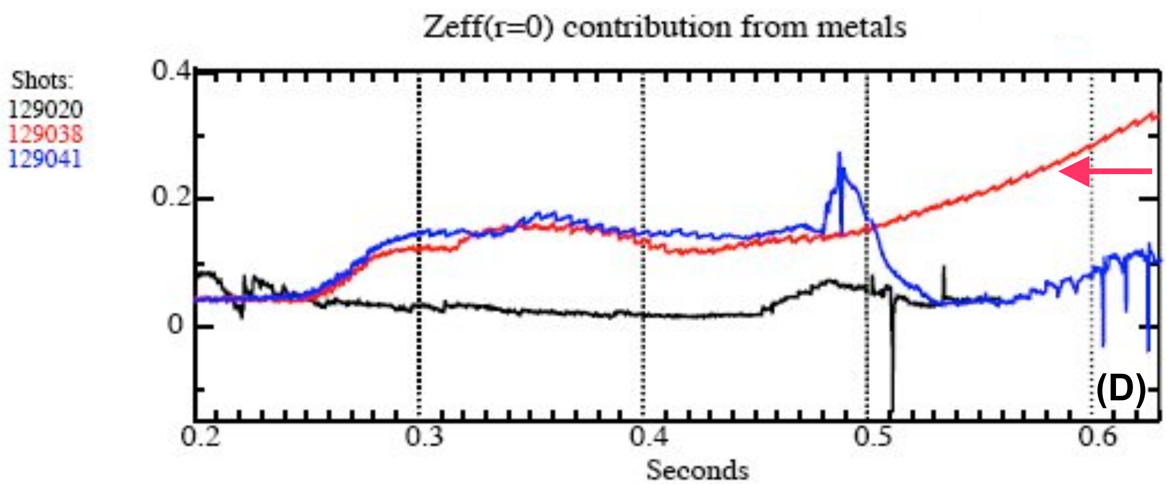
• Li Deposition Before Shot: 70 mg/min for 10 min. Total: 5734 mg



• Electron density rises

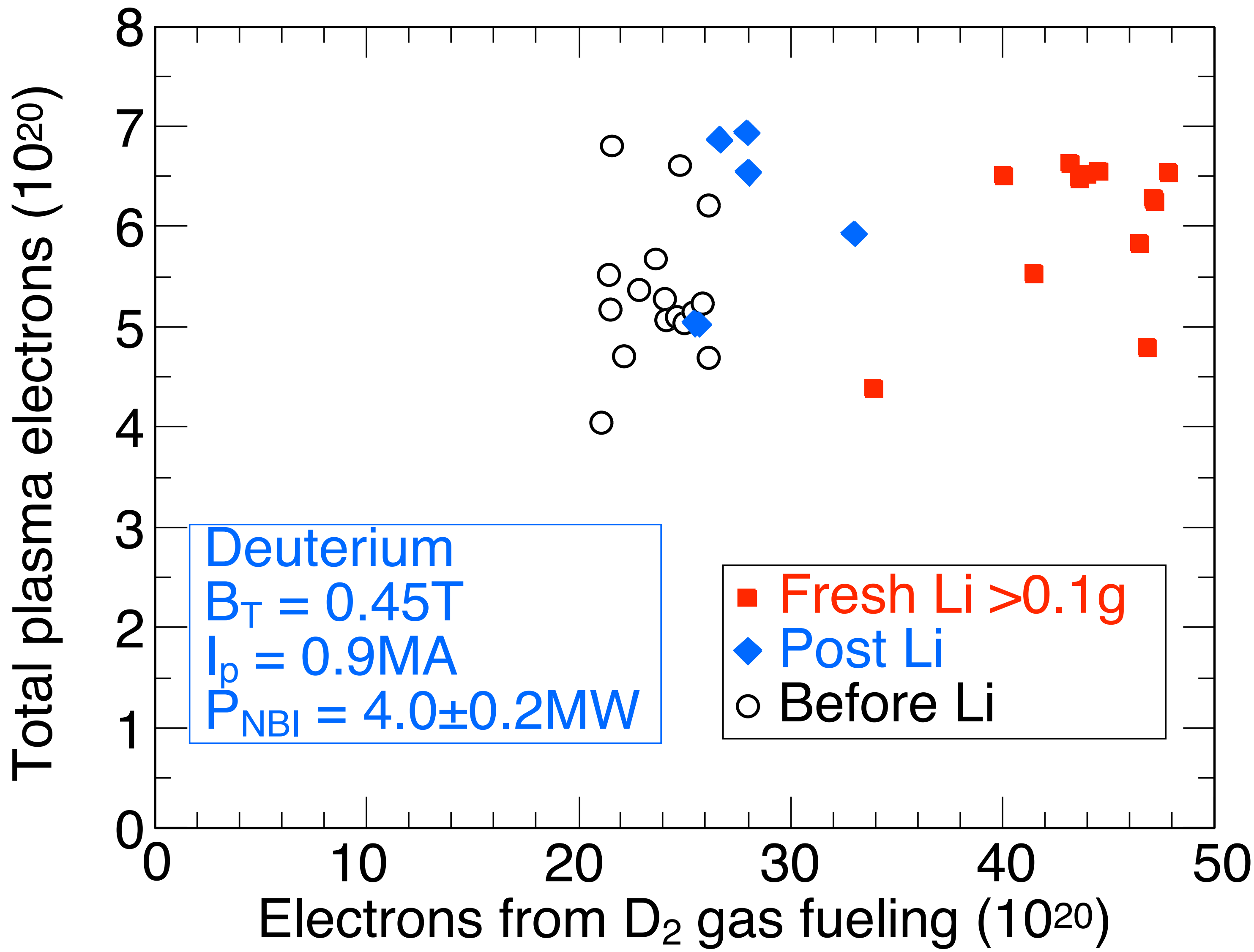
• Neutron rate decreases

• Core deuterium density does not increase

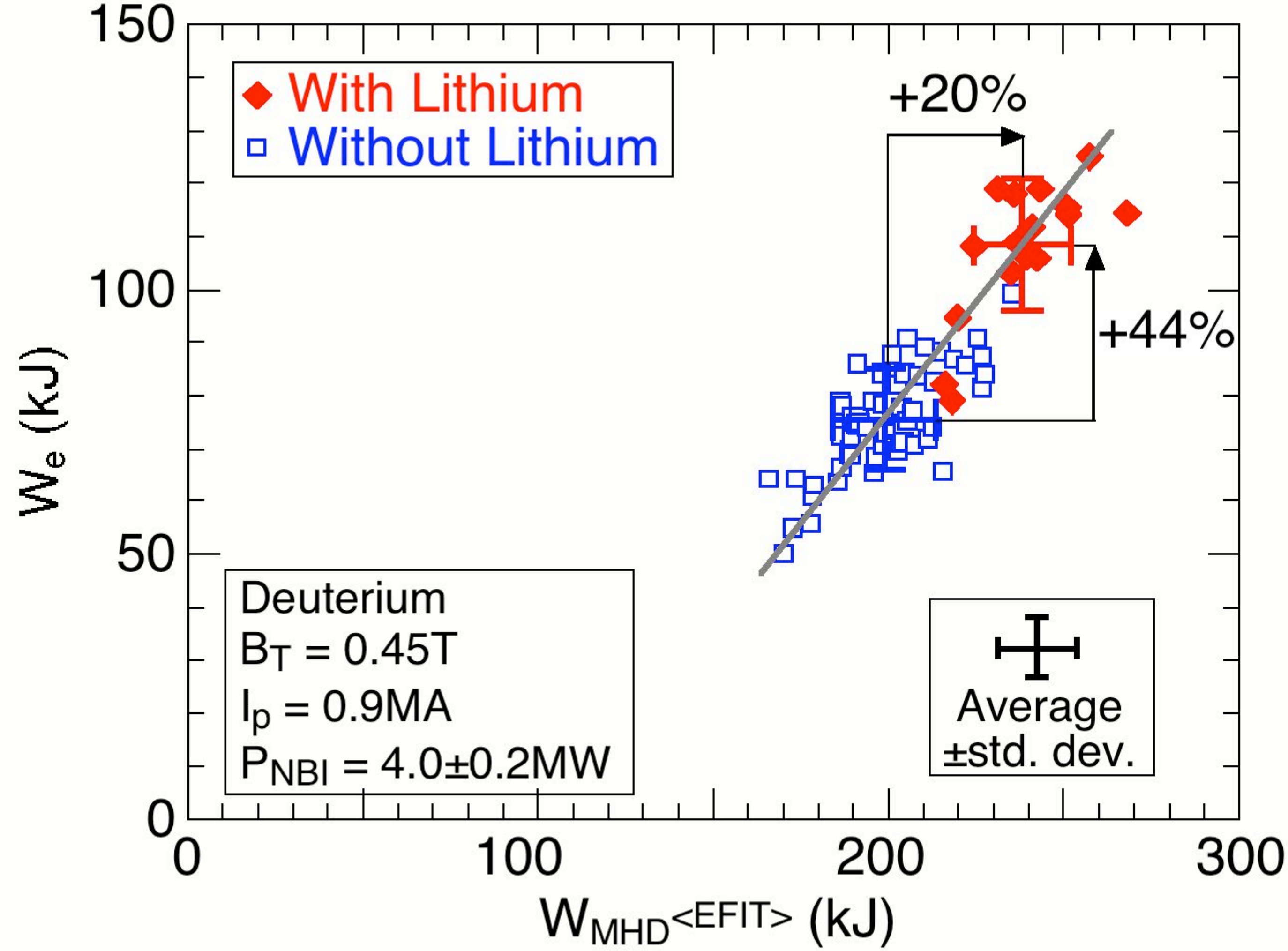


• Rising Z_{eff} with lithium PFC coatings suggests impurities as cause of density increase

Lithium edge conditions require large fueling increases to maintain density

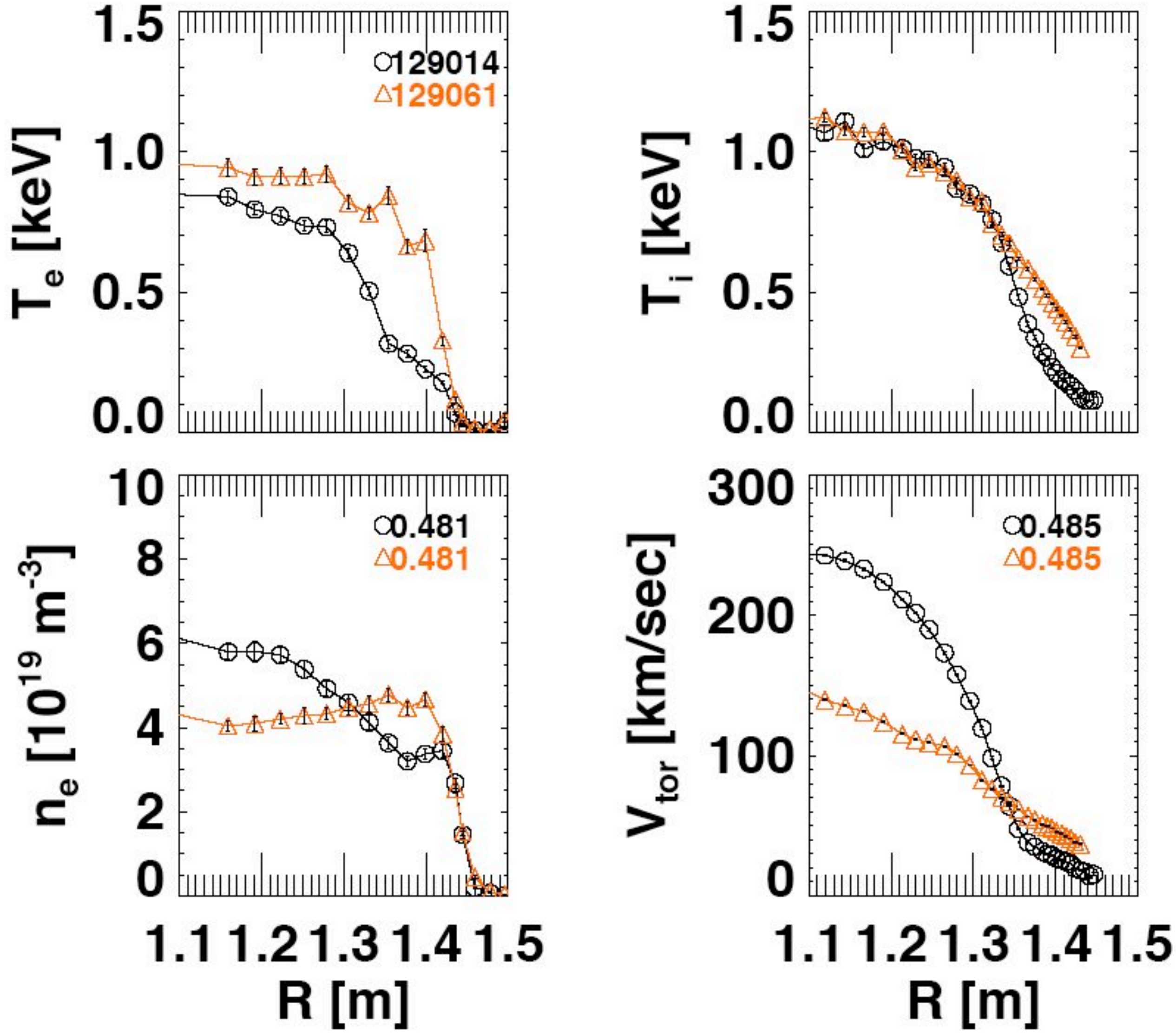


Stored energy (W_{MHD}) increases after lithium deposition mostly through increase in electron stored energy (W_e)

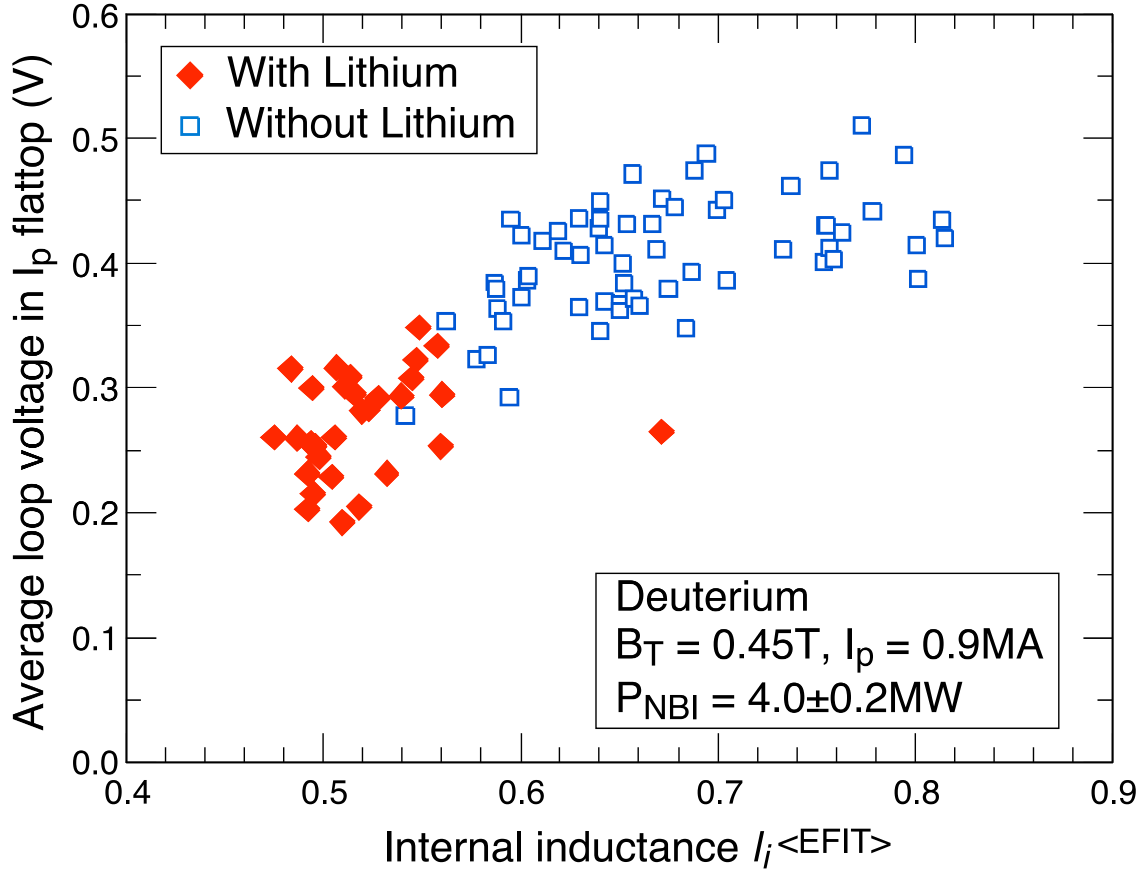


- Data sampled at time of peak W_e

Lithium edge conditions increased pedestal electron and ion temperature



Reduced OH flux consumption observed in plasmas with lithium-coated PFC’s



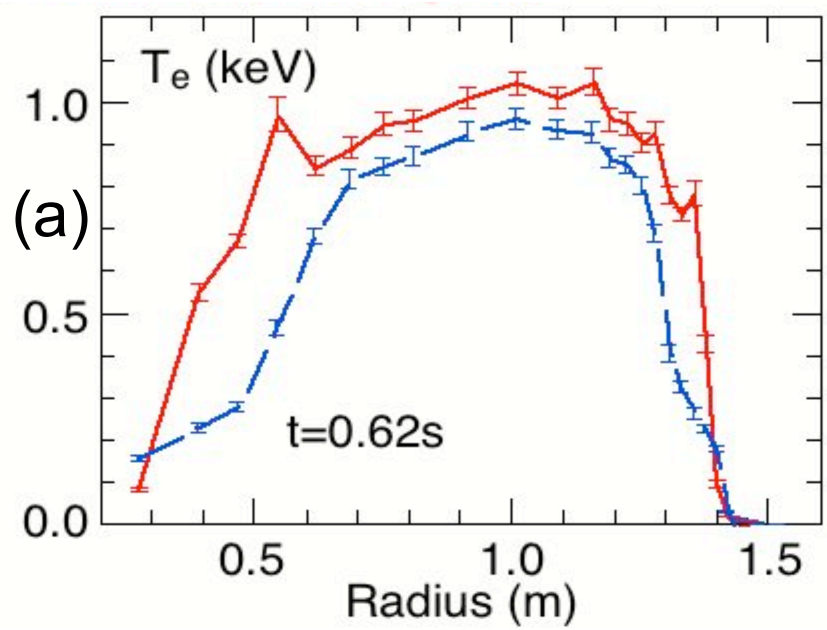
Lower average loop voltages mean more efficient flux consumption in NSTX discharges with lithium coatings on plasma facing components

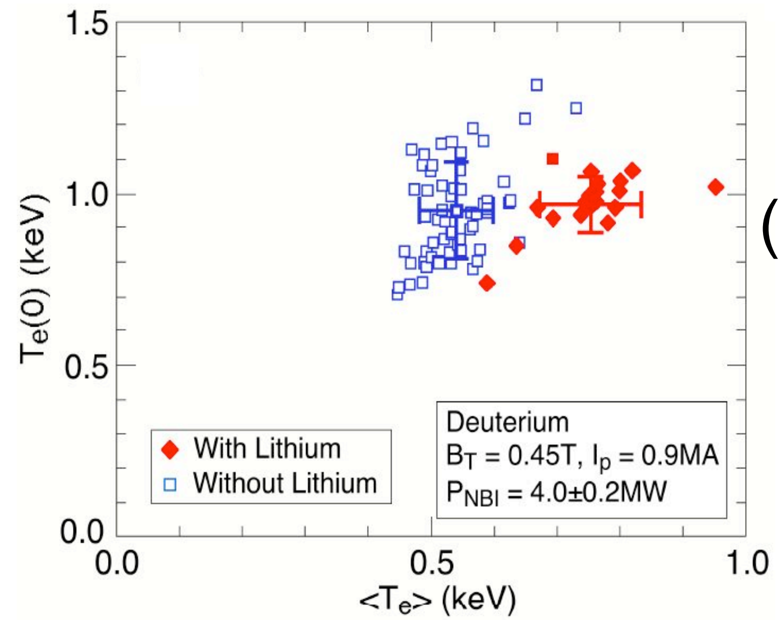
Effect of lithium PFC coatings on electron temperature profiles could affect flux consumption

NSTX

- **Typical example of temperature profile broadening (a)**
  - **Consistent tendency across shots with lithium PFC coatings (b)**

(a)





(b)

- **Internal inductance decreases as temperature profile broadens**
  - **Occurs in spite of higher Z_{eff}**

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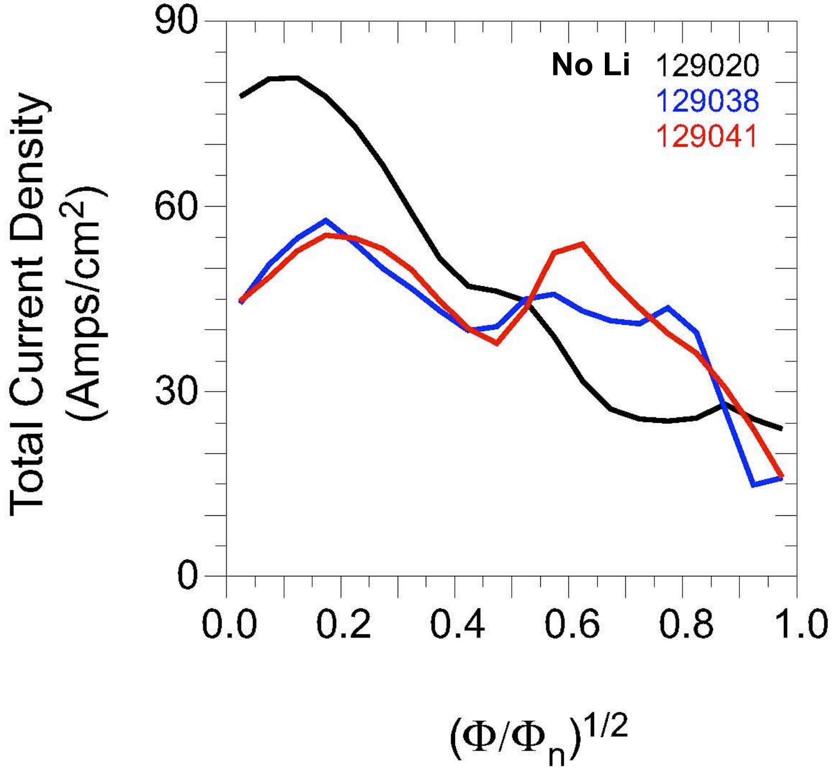
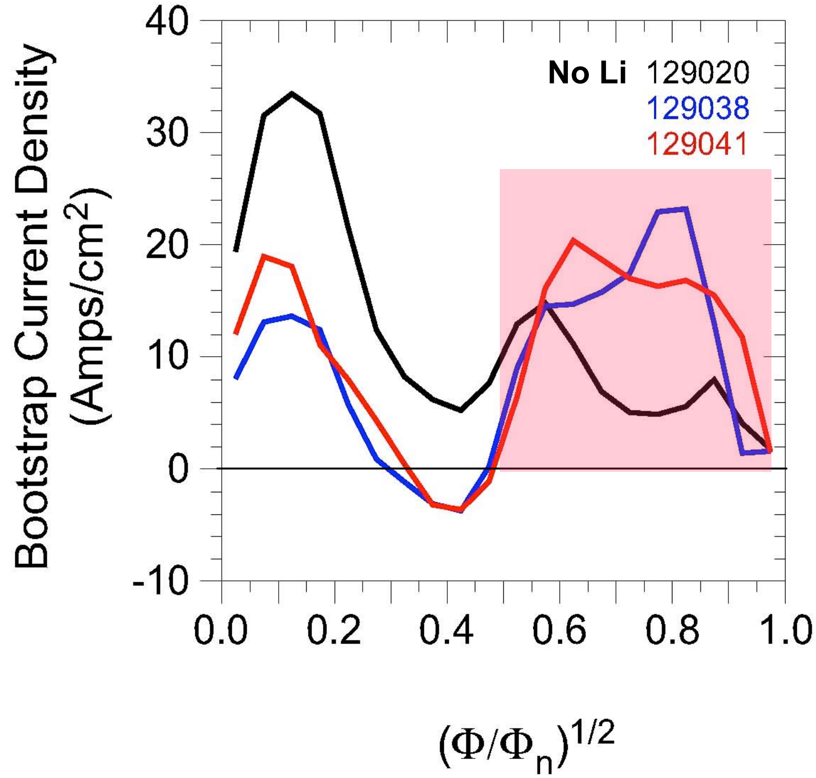
• **Lithium Edge Conditions Yield ELM Suppression**
• **TRANSP Analysis Finds Increase in Edge Current**

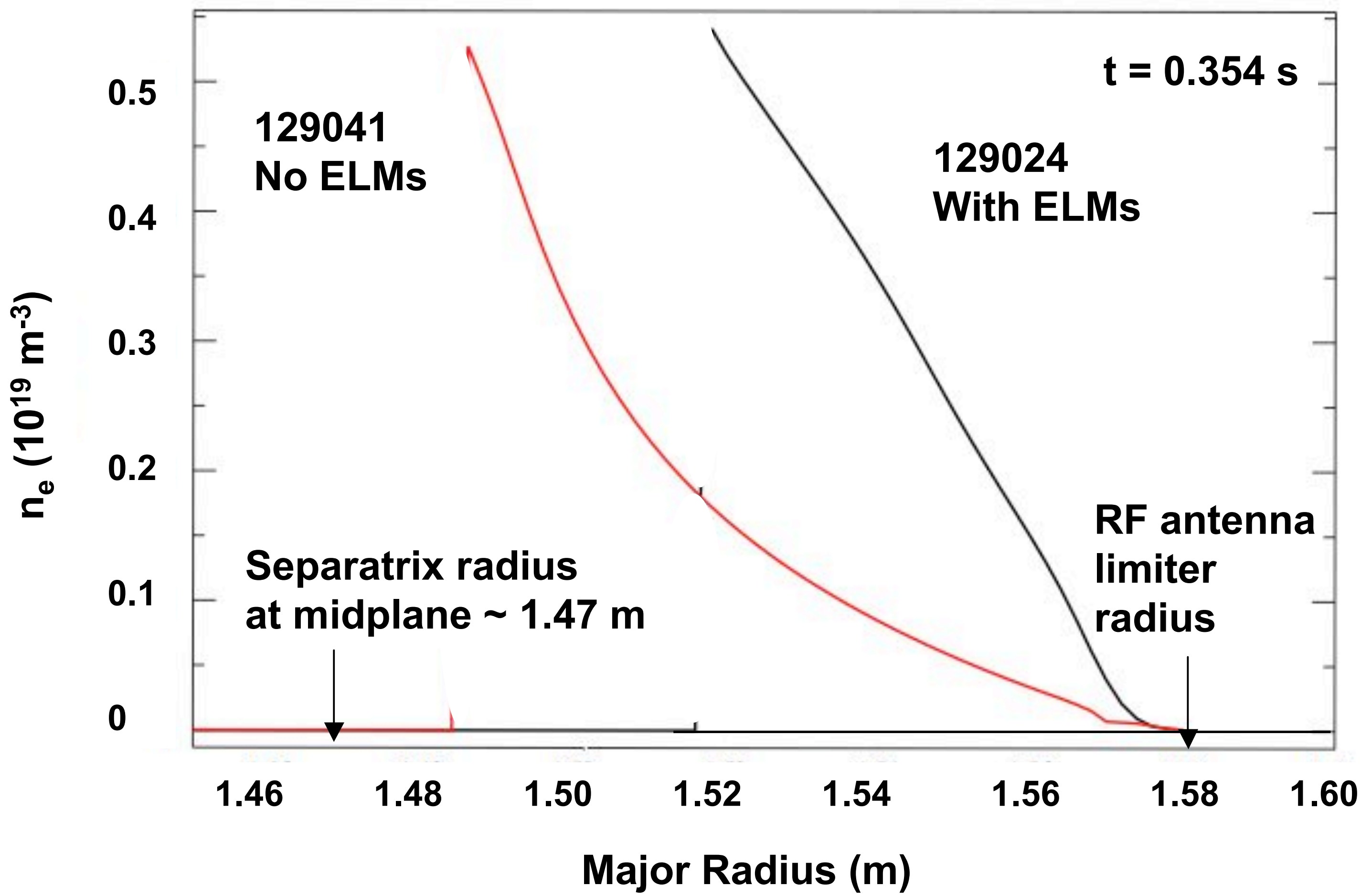




- **Higher pedestal gradients raise edge bootstrap current**
  - **Increase indicated by TRANSP transport calculations**
  - **Consistent with ELM suppression and second stability**

Measurements of scrapeoff layer profiles* indicate density reduction with lithium coatings

NSTX



*J. B. Wilgen et al., Rev. Sci. Instrum. **77,** (2006) 10E933.

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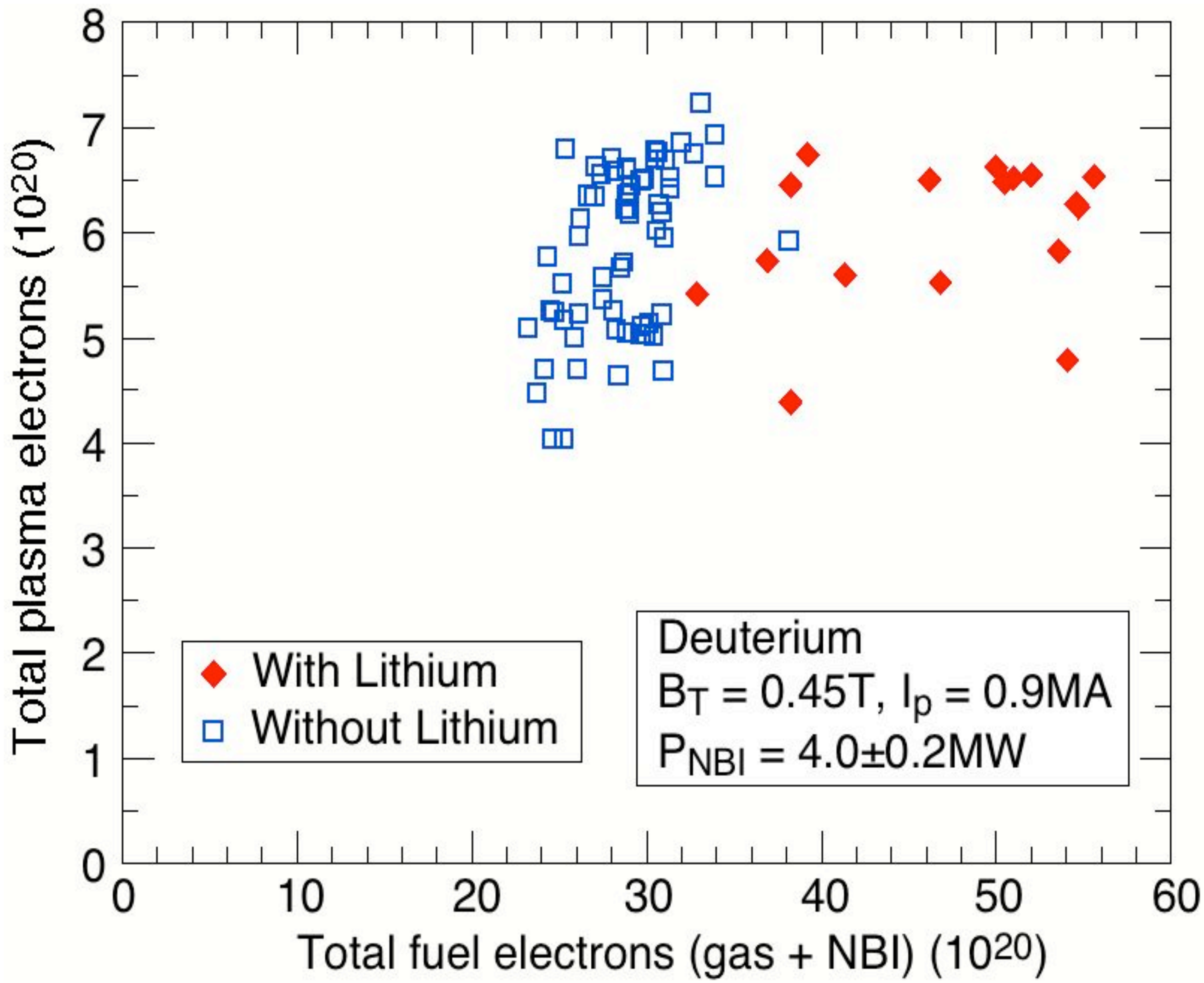
Higher discharge fueling needed with lithium-coated NSTX PFC's shows evidence for deuterium pumping



UEDGE Multi-fluid Transport Code used to model dependence of edge profiles on recycling

NSTX

- Mesh based on experimental equilibrium with one coordinate following flux surfaces.
- Second coordinate orthogonal except near divertor surfaces.
- Solve equations for n_i, T_e, T_i, $u_{||}$, ϕ,

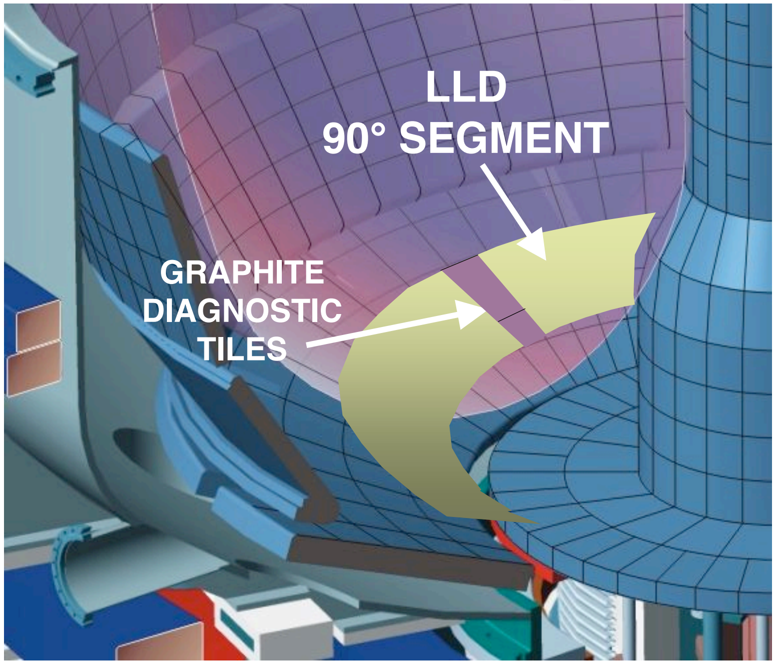
For modeling of effects of changes in recycling:

- Adjust transport coefficients until edge temperatures and densities match data from multipoint Thomson scattering diagnostic for existing NSTX plasmas
- Generate new profiles by varying recycling coefficient

UEDGE calculations performed for new NSTX liquid lithium divertor (LLD) to be installed for 2009 run

NSTX

- Location - lower outer divertor in four 90°sections.
- Width - 20 cm starting 5 cm outboard of CHI gap.
- Shape - replaces present graphite tiles.
- Structure - 0.01cm Mo flame-sprayed on 0.02 cm SS brazed to 1.9 cm Cu. Resistive heaters and cooling lines maintain 200-400°C.
- Li Loading - 2 lithium evaporators.



- Each toroidal section electrically grounded to vessel at one mid-segment location to control eddy currents
- Each toroidal section fastened at 4 corners to divertor copper baseplate with fasteners providing structural support, electrical isolation, and accommodating thermal expansion (design adopted from JET PPPL collaboration)
- Narrow graphite tile transition regions between sections contain thermocouples, Langmuir probes, and magnetic & current sensors

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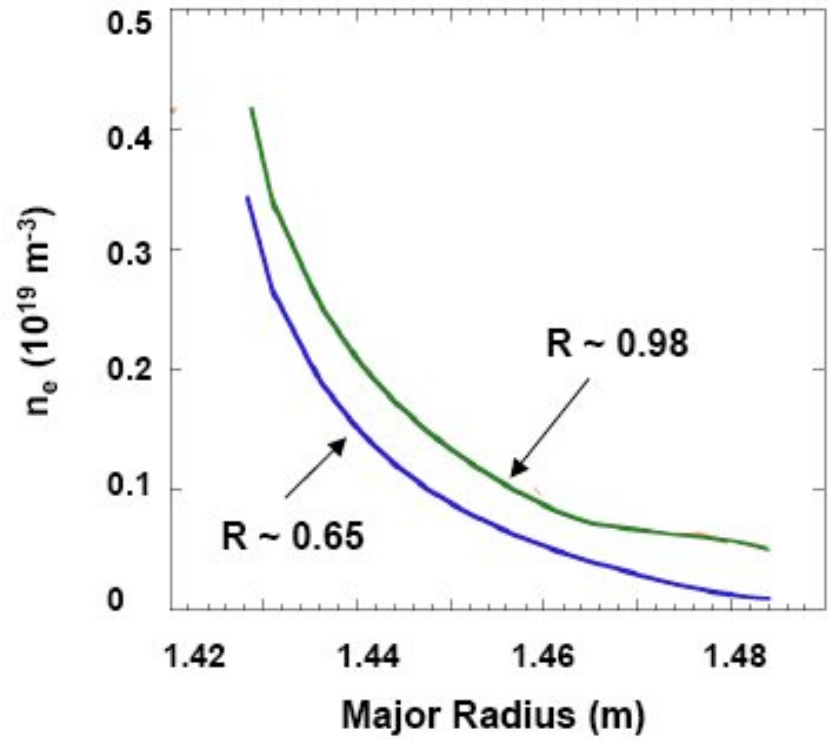
UEDGE modeling in progress to determine change in recycling based on edge density data



- **Simulations show dependence of density profile as function of recycling coefficient**
- **Curves match shape of density profile from plasmas with lithium coatings on PFC's**
- **Calculations to not match linear density rise seen without lithium coatings on PFC's**
  - **Suggests need to investigated differences in transport as well as recycling in modeling**

Summary

- Recent experiments on NSTX have demonstrated improved plasma performance with lithium-coated PFCs
  - Two LITER evaporators deposited lithium on the lower divertor target for up to 10 min between discharges at total rates reaching ~80 mg/min
    - Increased shot repetition rate possible with elimination of HeGDC
  - New shutter mechanism prevented evaporation of lithium during glow discharge cleaning and plasma shots

- Effects of lithium PFCs on NSTX plasmas include:
  1. Reduced time between discharges for glow discharge cleaning required to achieve H-mode
  2. Reduced plasma density in early phase of discharge
  3. Suppression of ELMs
  4. Improved energy confinement
  5. Reduced flux consumption and increased pulse length
  6. Increased pedestal electron and ion temperature
  7. Reduced SOL plasma density - consistent with lowered recycling