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NSTX Conditioning Experiment Using Injected Lithium Powder (SLMP^{TM})

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D.K. Mansfield, H.W. Kugel, J. Timberlake, L. Roquemore, R. Kaita, R. Majeski, M. Bell, S. Kaye, S. Paul, V. Soukhanovski, L. Zakharov and the NSTX team

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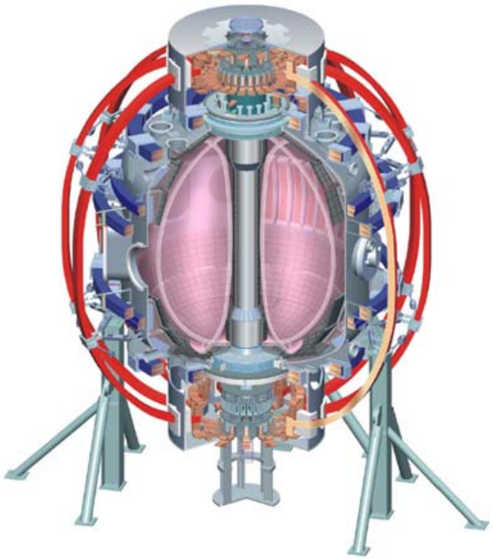


Description of the Experiment

- During the 2007 NSTX experimental campaign a brief attempt was made to condition the divertor strike points using newly-available lithium powder injected into the plasma scrape-off layer (SOL). The purposes of the experiment were to determine: (1) if dispersed powder particles would ablate and evaporate in the SOL and (2) whether or not the resulting Li ions would be transported along open field lines until they were eventually implanted in the divertor.

- The original intent of this work was also to look for real-time beneficial effects during the discharges into which Li powder was injected (the target discharges). As experimental difficulties were encountered, however, the search for conditioning effects took place instead during the discharges immediately following the target discharges (i.e. the discharges of interest).

- Injection into the target discharges was accomplished using the existing 8-barrel NSTX lithium pellet injector (LPI See Fig 4). Special heavy sabots with an internal telescope design (Fig 5) were developed in order to ensure that the powder injection velocity would be as low as practical (~ 5 m/sec See Fig 6) and that the flux of powder particles would be dispersed over as long a time as possible (~ 20 msec/barrel ≡ sabot length / sabot speed).

Description of the Experiment (Continued)

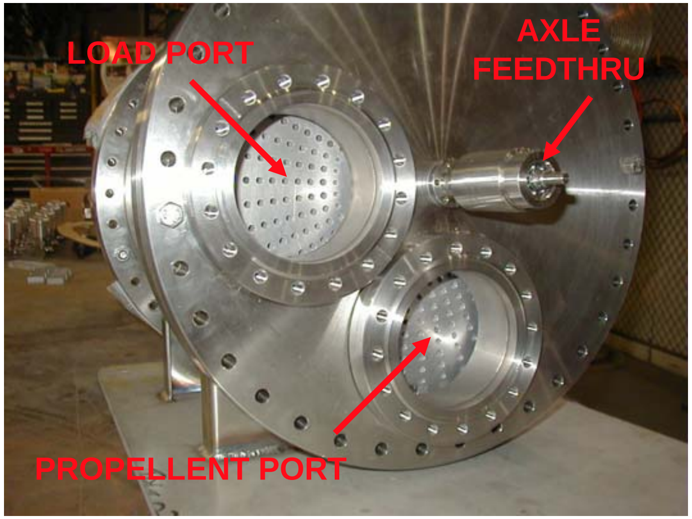
- In practice, however, because the sabot speed was so low, the He gas used as a sabot propellant had ample time to leak around the sabots (Fig 5) and to enter the NSTX vacuum chamber at unacceptable levels (~ 5TL). This inadvertent gas puff had two adverse effects: (1) it caused the target plasma to disrupt (independent of whether or not Li powder was injected) and (2) it entrained Li powder particles into the discharge rather than allowing them to enter ballistically - and therefore slowly.

- The Li powder employed (SLMP^{TM}) was supplied by FMC Corporation. Each individual spherical particle has an average particle diameter of 45 – 50 μm and is stabilized against reaction with air by a 50 nm continuous layer of microcrystalline lithium carbonate by a proprietary process developed at FMC. The resulting stabilized powder particles are on average about 98.5% Li and 1.5% Li_2C0_3 by composition. A scanning electron microscope image of these particles is shown in Fig 7.

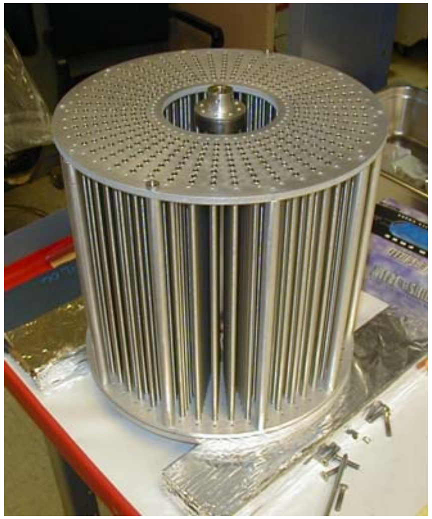
- Despite the technical difficulties encountered, useful information was gleaned from both the target discharges and from the subsequent shots of interest. Both types of discharges are discussed below.

NSTX Lithium Pellet Injector (LPI)
Lithium Powder (SLMP^{TM}) Injected Using Modified Sabots

- **LPI adapted for powder injection by changing sabot design**



OUTBOARD VIEW

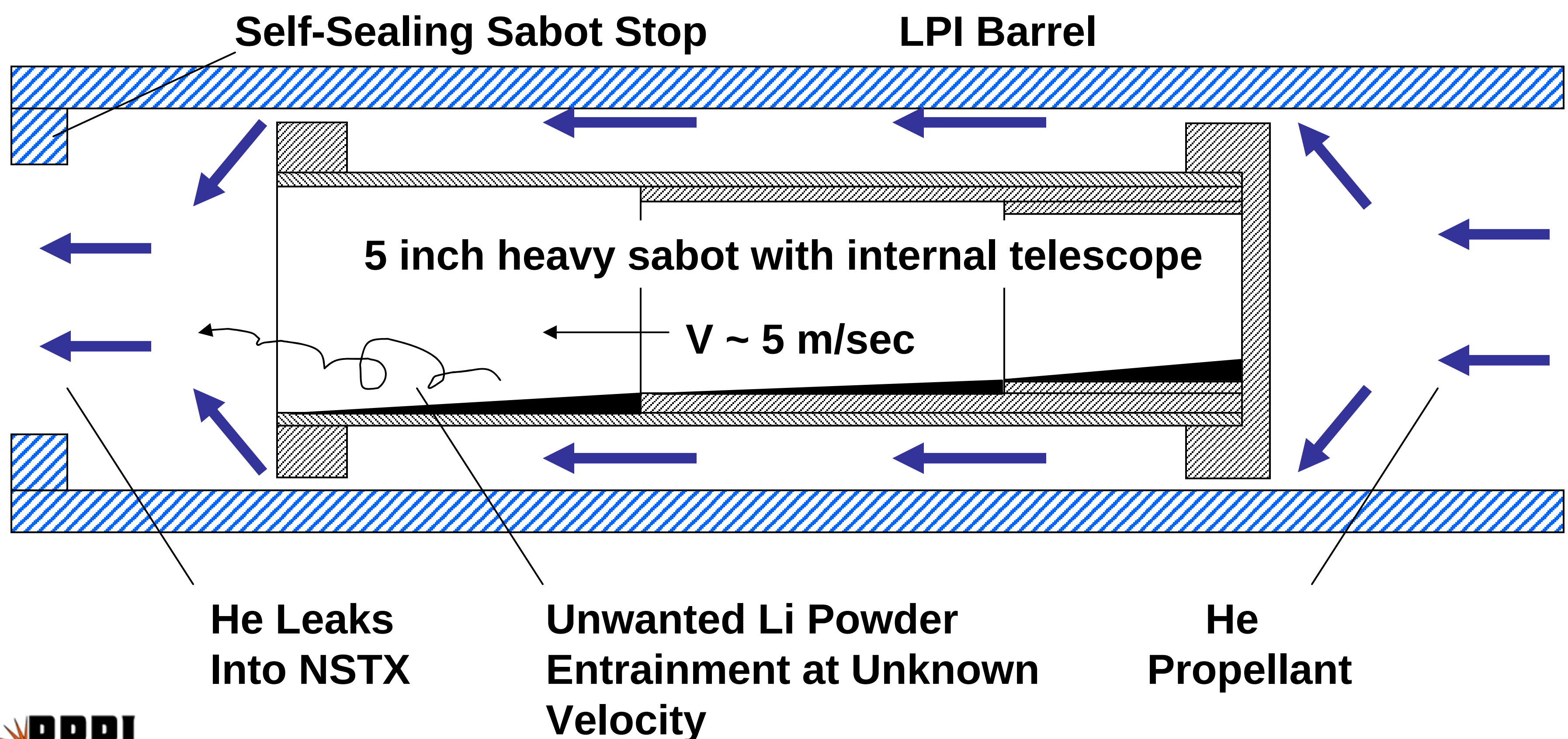


400 BARREL TURRET

- **Sabot style injector designed for small pellets ($\leq$ 5 mg)**
- **50 – 200 m/s radial injection speed (= sabot speed)**
- **1 – 8 pellets per shot (8 barrels available)**
- **400 pellet capacity**
- **Long, heavy sabots with internal telescope used for powder**

The Problem with the Long, Heavy Sabots in the LPI

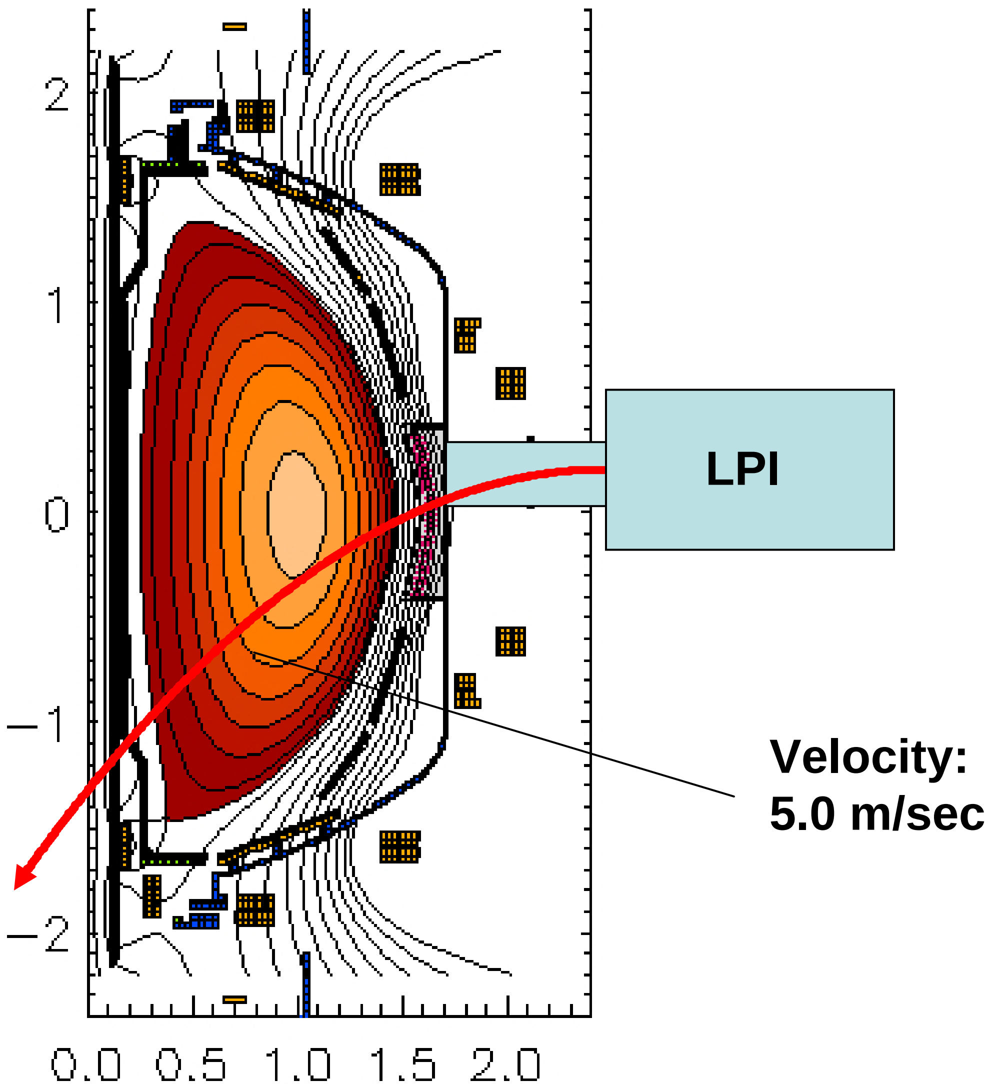
- **Heavy telescoping tubes were used to prevent bunching <u>and</u> add mass (1.7 gm) to reduce sabot speeds. Unfortunately, the resulting long sabot transit times permitted He propellant to leak around the sabots and to entrain the Li powder into NSTX instead of allowing the powder to enter NSTX ballistically at ~ 5 m/s.**



NSTX Ballistic Trajectory (5 m/sec) from LPI

This diagram shows a flux plot for a lower single null H-mode discharge similar to those used for both the target shots and the shots of interest.

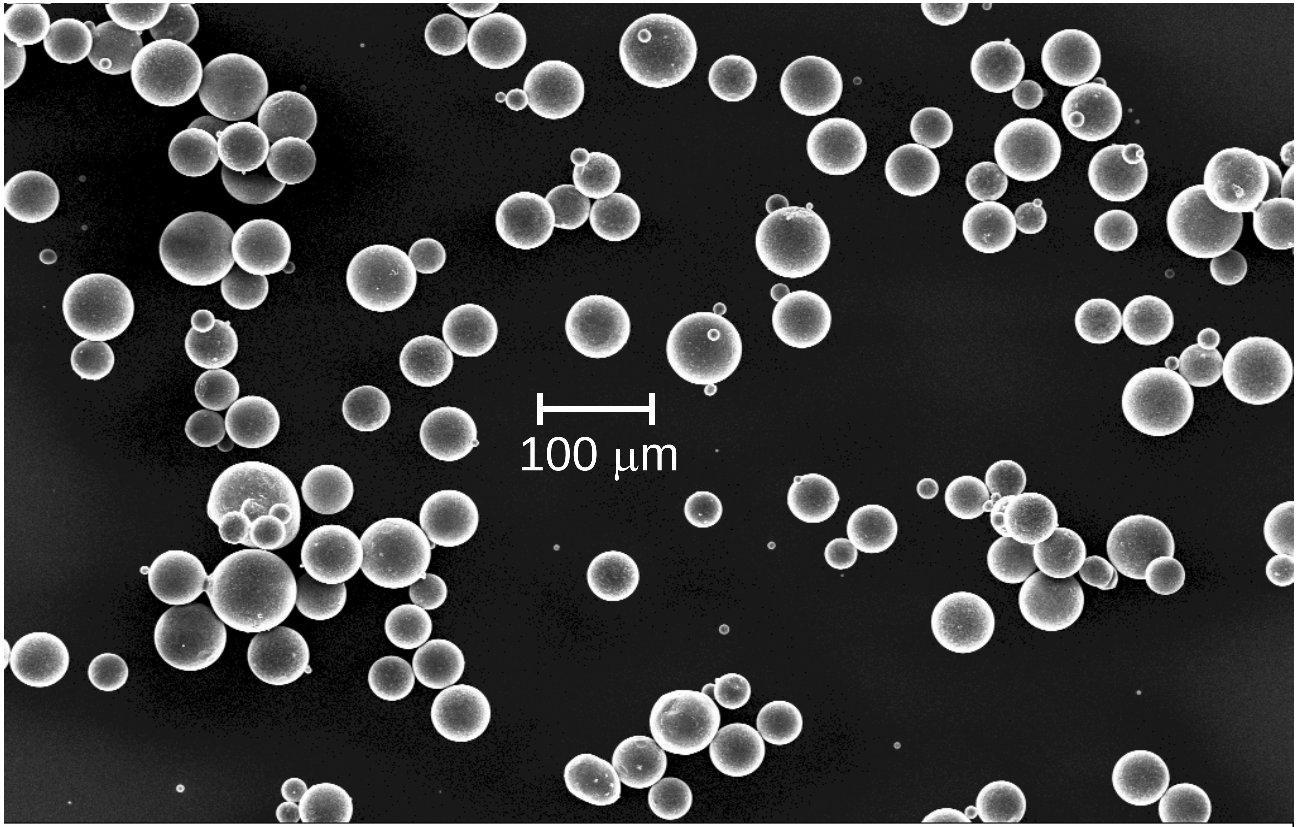
The powder ballistic velocity was limited to only 5 m/sec in order to limit penetration as much as possible to the SOL.



A Scanning Electron Microscope Image of FMC Stabilized Metallic Lithium Powder (SLMP™)

NSTX

- Average spherical particle diameter = 45 - 50 μm
- Each particle coated with Li_2CO_3 to reduce reaction with air
- Composition : 98.5 % Li , 1.5 % Li_2CO_3



Raith 150	100μm	EHT = 10.00 kV	Signal A = InLens	Date :7 Apr 2006
Mag = 100 X		WD = 5 mm	Aperture Size = 30.00 μm	Time :13:47:04

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What was Learned from the Target Discharges ?

• **Powder dispersed for durations of ~ 80 msec. Longer (~ 4x) than calculated from ballistics (sabot length/sabot speed ~ 20 msec). Hence powder was introduced into NSTX via entrainment by propellant gas, not ballistically at ~ 5 m/sec. (See Figs 10 - 13)**

• **This conjecture was bolstered by post-experiment inspection of LPI when significant amounts of powder were found in all barrels containing sabots which were pre-loaded with a known mass of Li powder *but were not fired* during the experiment. The best estimate under these circumstances is that ~ 5 - 50 mg of Li powder was injected into any particular target discharge.**

• **Encouragingly injected Li *did* ablate and ionize in the plasma SOL. Further, Li ions *did* follow open field lines into the NSTX divertors. (See Figs 12 - 13)**

Images Taken During the Target Discharges

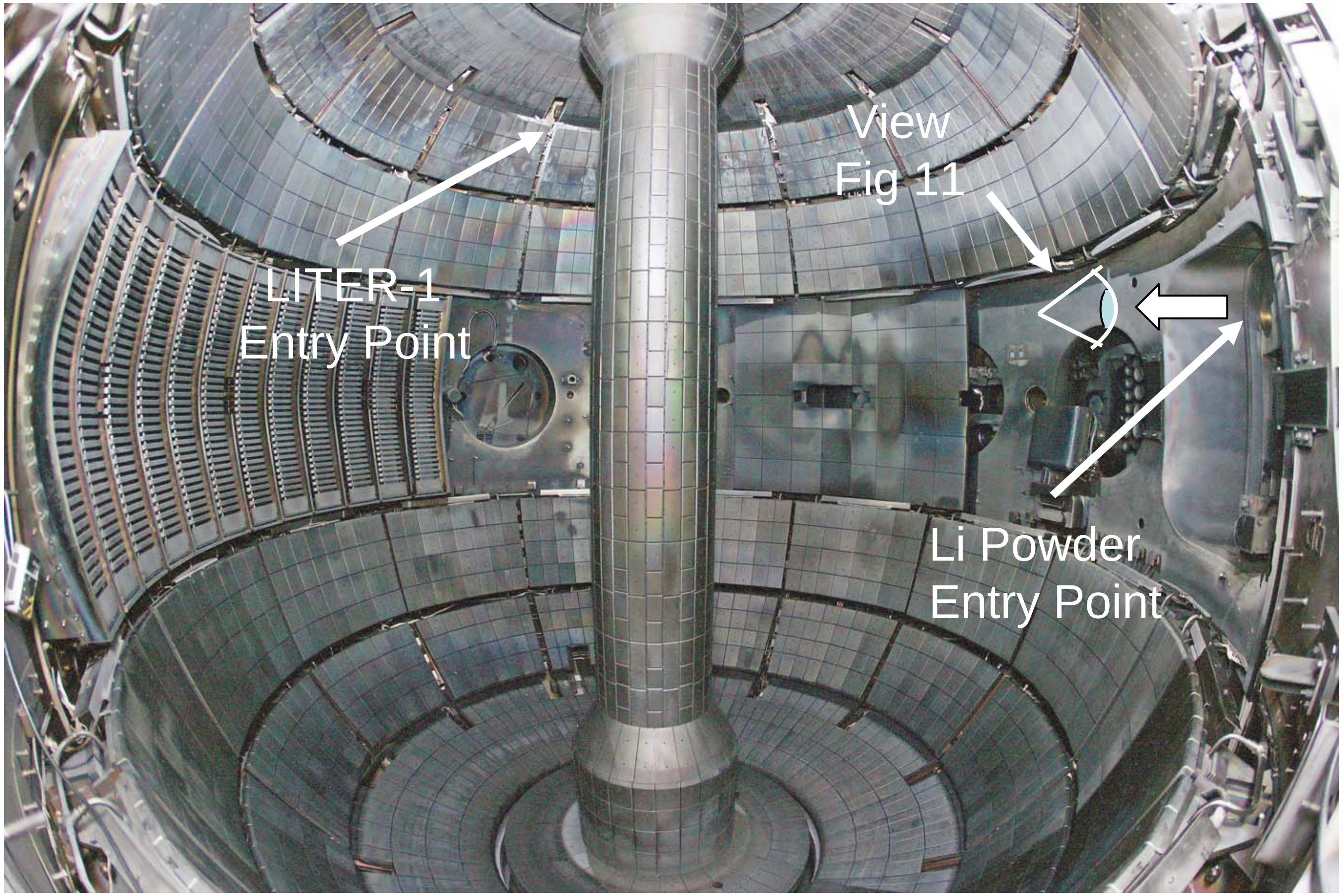
- **Shown in Fig 10 is a wide angle view of the interior of NSTX. The Li powder entry point is indicated. This is the view employed for Figs 12 & 13. The view in Fig 11 is of the injection point seen “head on”.**

- **Fig 11 displays the injection site as seen “head on”. In this diagram are shown four frames from a high-speed camera in white light. A time history of Li^{+1} emission is also shown. Clearly, Li powder entered NSTX for a duration of 80 ms. This was four times longer than expected from ballistic considerations.**

- **Shown in Fig 12 are four frames from a high-speed camera showing images taken in white light. Clear streaming toward the upper x-point is apparent. It also appears that lithium reached the lower divertor.**

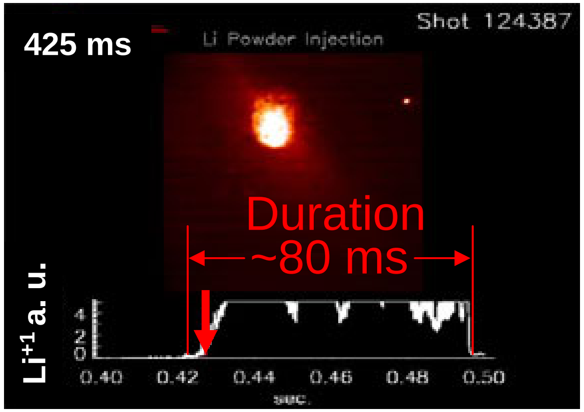
- **The same types of images taken with a Li^{+1} filter are shown in Fig 13. These images clearly show lithium ions streaming toward the upper x-point as was seen in Fig 12. Also apparent is the rapid neutralization of the ions as they encounter the divertor surface.**

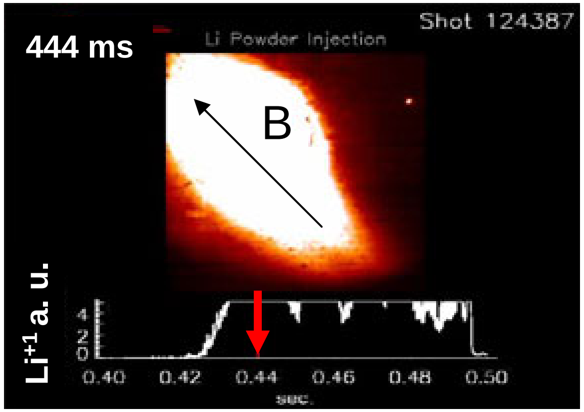
Wide Angle View of Interior of NSTX

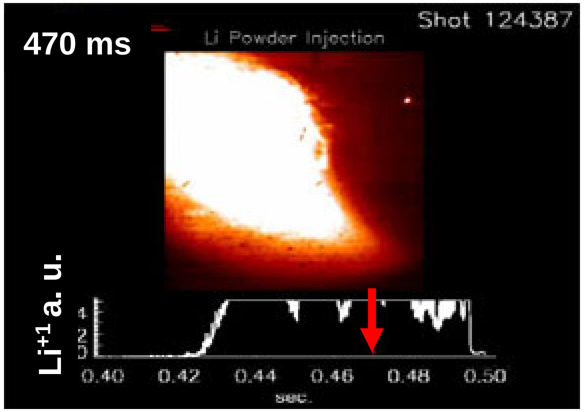


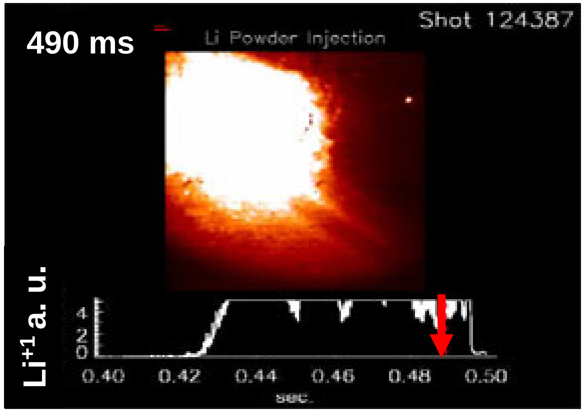
The Measured Duration of Li Powder Injection was Much Longer (4X) than Expected from Ballistic Calculation

- Indicates that the powder was entrained with the He propellant and not “thrown in” slowly (~ 5m/sec) and ballistically with the sabot



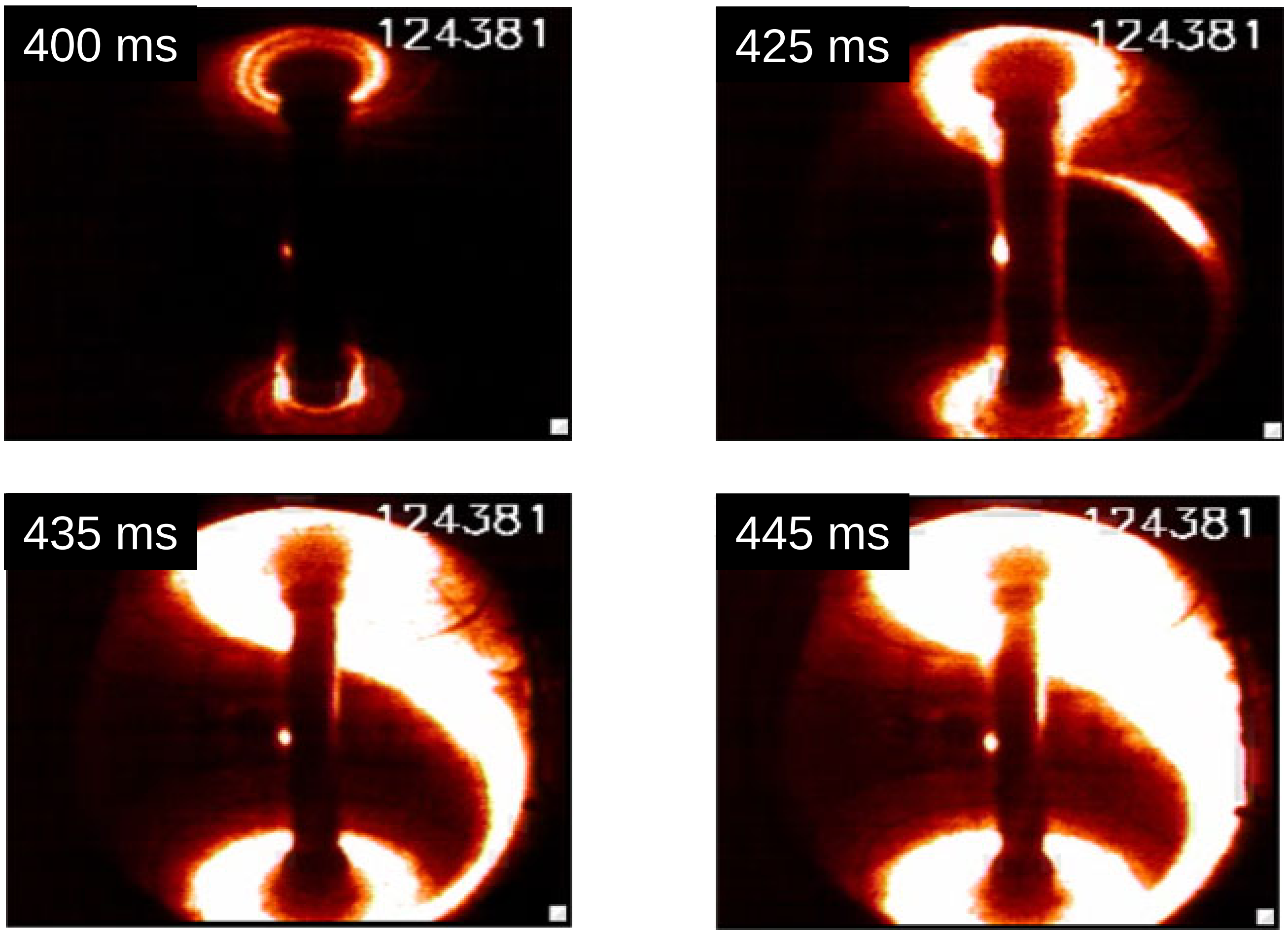






White Light Movies Show Ablation of Li Powder in SOL. Li Ions Follow Open Field Lines to Divertor(s).

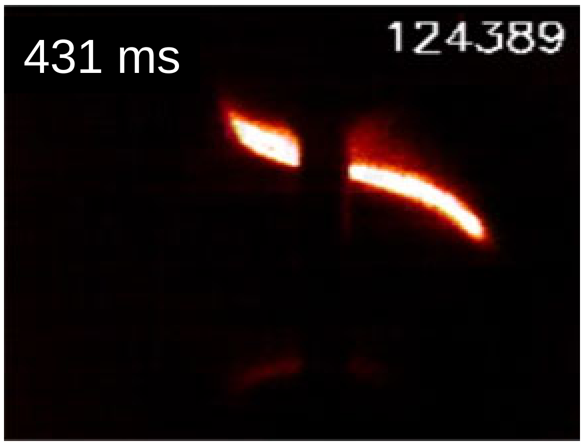
- Preferential drift toward upper x-point during LSN H mode

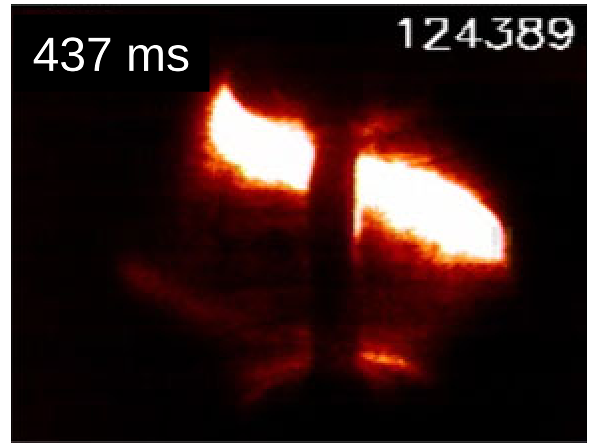


Initial Injection
Li Powder

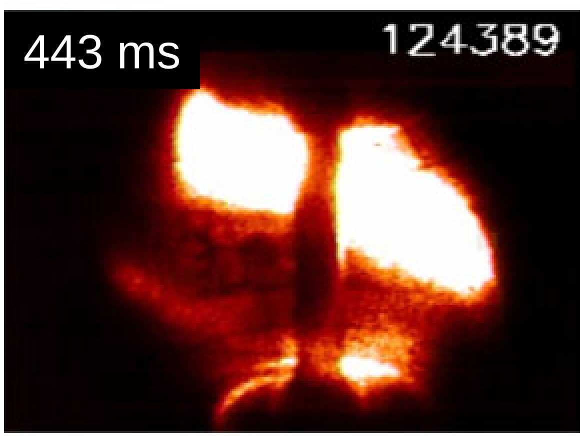
Li^{+1} Movies Show Clear Drift Toward Upper X-Point and Clear Neutralization In the Divertor Area

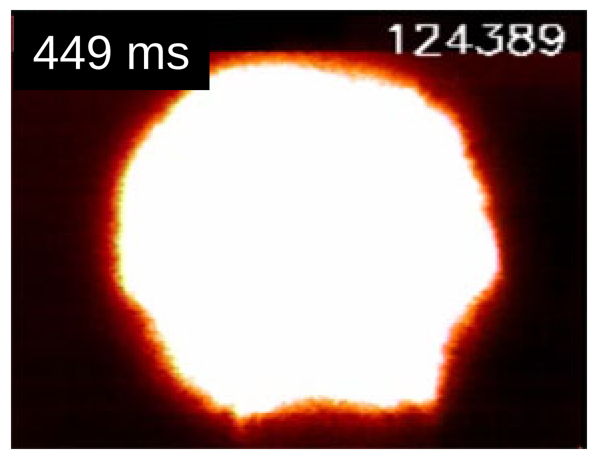
- Li+1 emission seen in SOL but absent near the divertor area
- Perpendicular spreading of Li emission in SOL also observed





Li Powder Entry Point





What was Learned from the Discharges of Interest ?

Some modest improvements in performance were observed in the shots of interest:

• A small decrease in line-average density was seen in each of the discharges of interest. Some of this decrease can be attributable to a delay in H-mode onset. (See Fig 15 - 17)

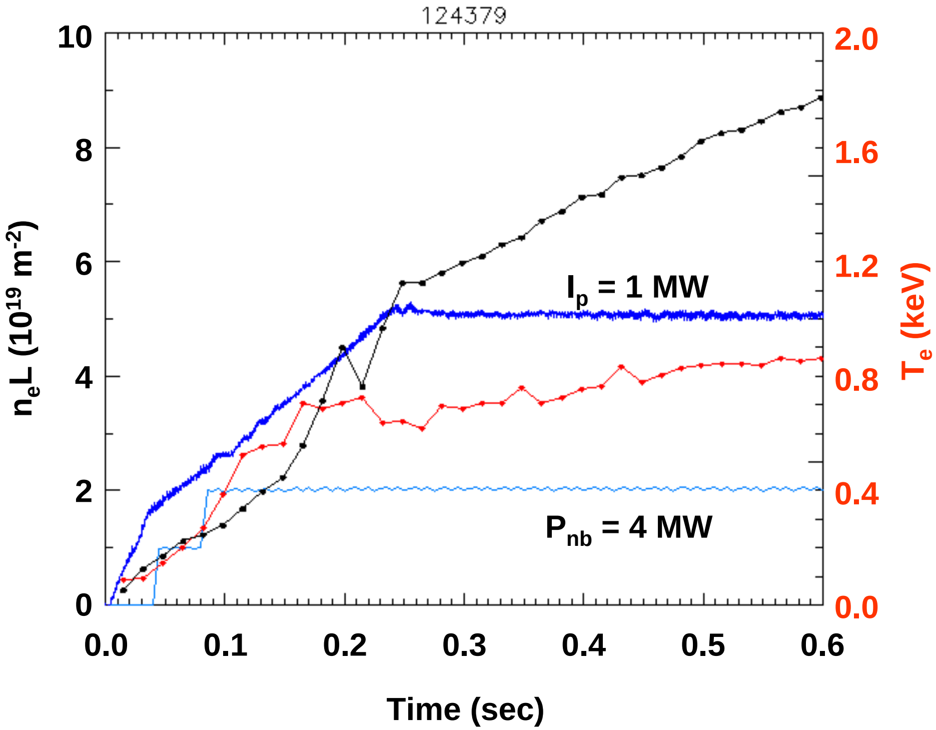
• A transient increase in central electron temperature was seen during each discharge of interest. This was even seen on a shot taken after an aborted discharge into which Li powder was injected mistakenly so that the powder ended up simply laying at the bottom of the NSTX chamber.

• A decrease in the radiated power as compared to the fiducial was another robust feature of the data. (See Fig 17).

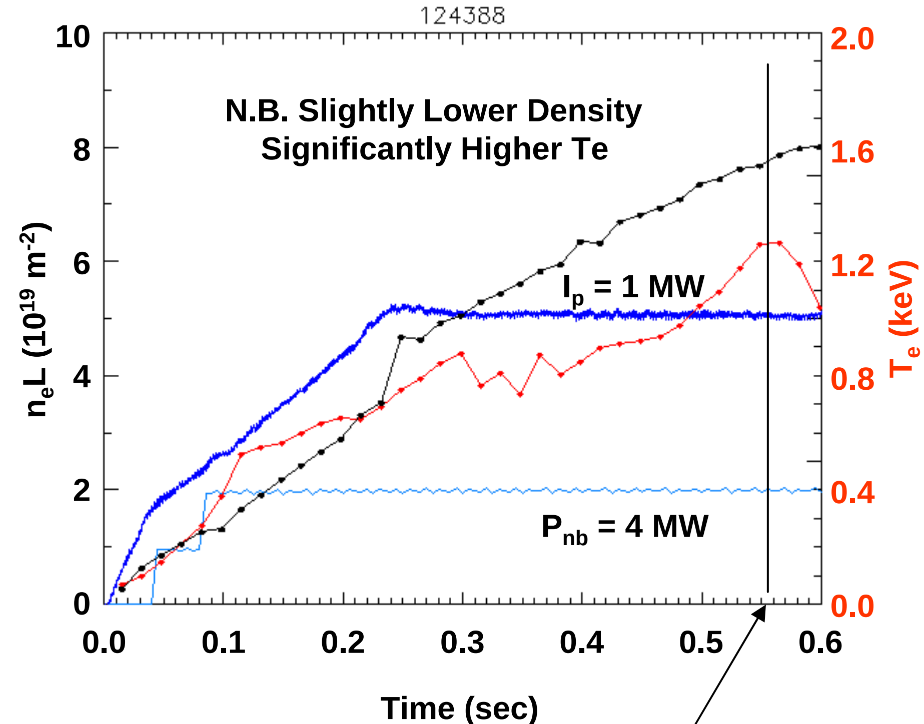
Comparison of Two Discharges: w & wo Li Powder Injection

- Slight lowering of ne – complicated by later H-mode transition
- Generally increased Te also reproducible transient increase

No Li Discharge



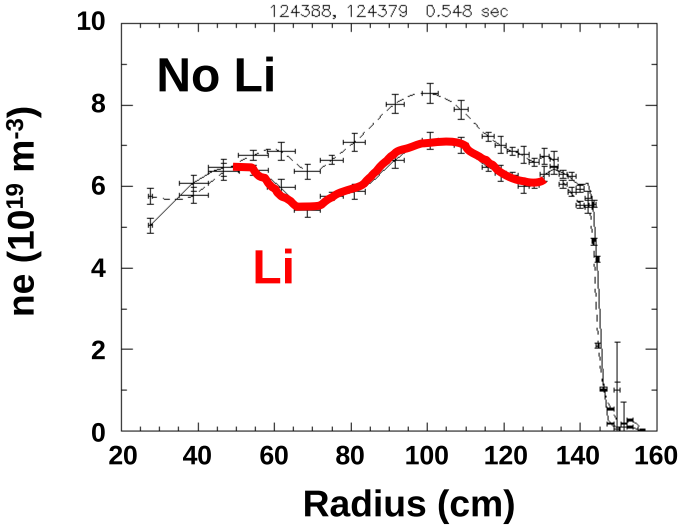
Discharge After Li Powder Injection

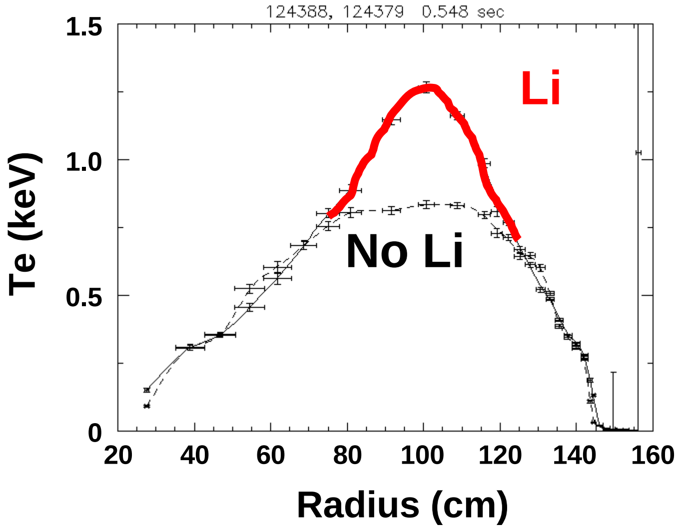


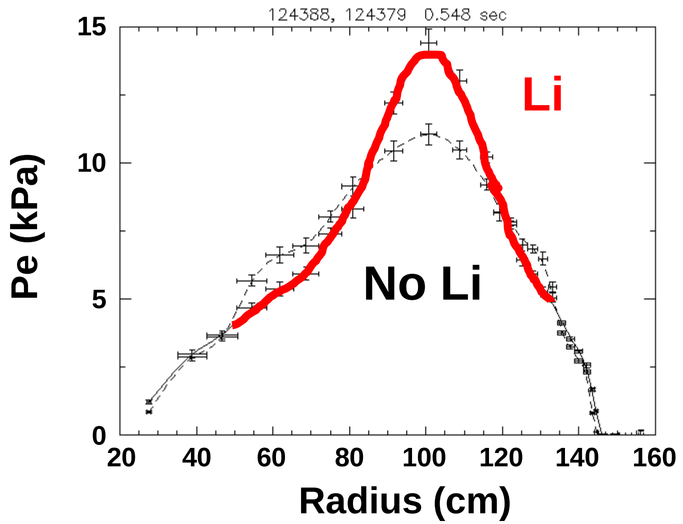
Profiles at this time shown in next figure

Thomson Scattering Profiles Taken During Transient Improvement Shown in Previous Figure

- **Slight decrease in ne, large increase in Te with Li Conditioning**







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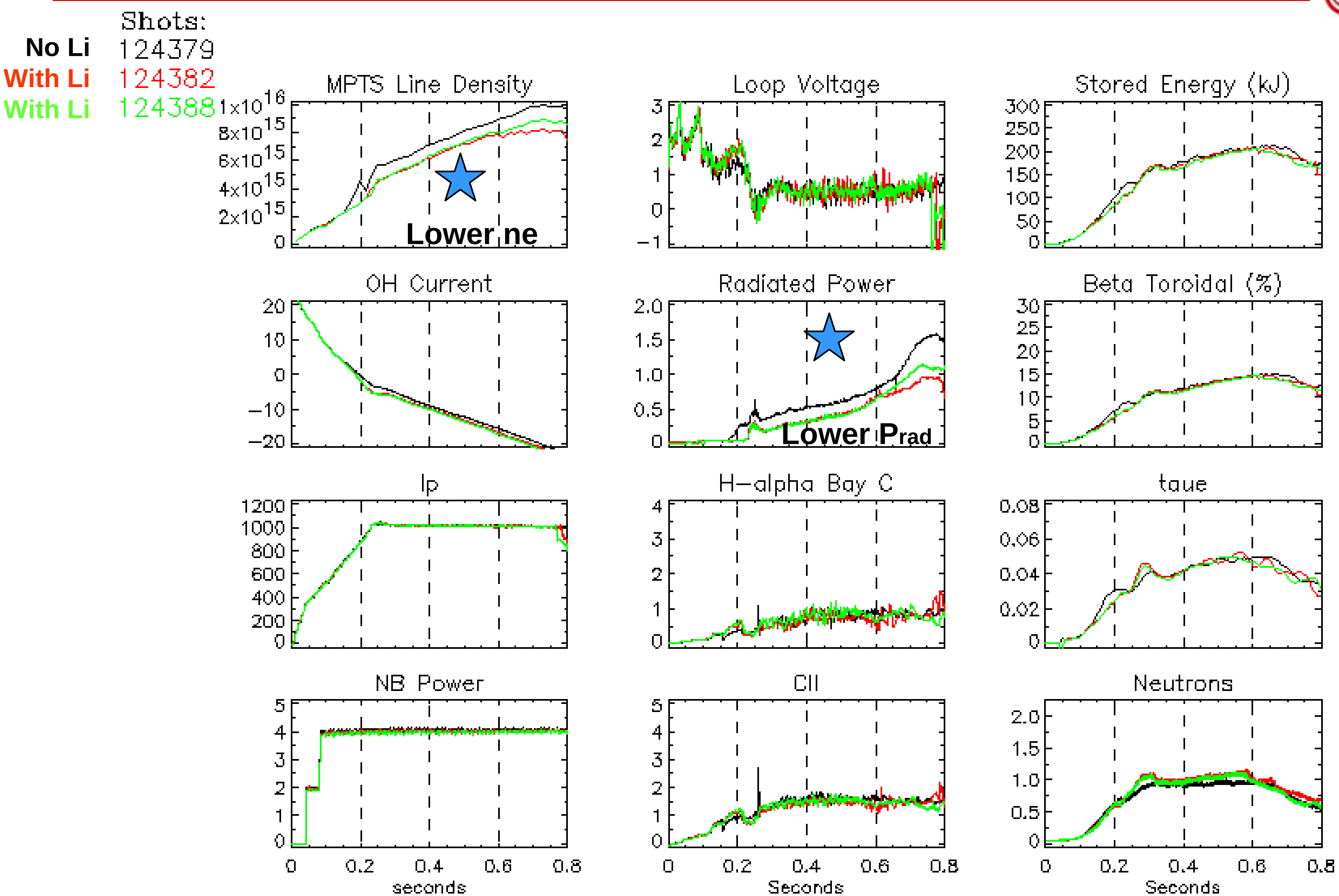
Further Effects of Lithium Powder Injection



Conclusions and Future Plans

NSTX

- The injection of Li powder was a partial success because some residual benefit from the target discharges was seen in the subsequent discharges of interest. It is clear, however, that an injection technology other than the LPI (with unwanted He leakage) must be employed in order to derive the benefit of Li conditioning in real-time during target discharges.

- Toward that end, a gravity-based injector is presently under development and will be tested during the 2008 NSTX run campaign. The essential elements of the new system will draw from the particle detection technology developed at MIT[1] as well as the shaker/dropper technology developed at NANL[2]. A few of the salient features of the new NSTX dropper system are shown in Figs 19 through 21.

- The new system will allow the injection of Li powder at low velocity (~4.5 m/sec) and without the introduction of any propellant gas. These features should allow for a more definitive test of Li powder efficacy to be carried out.

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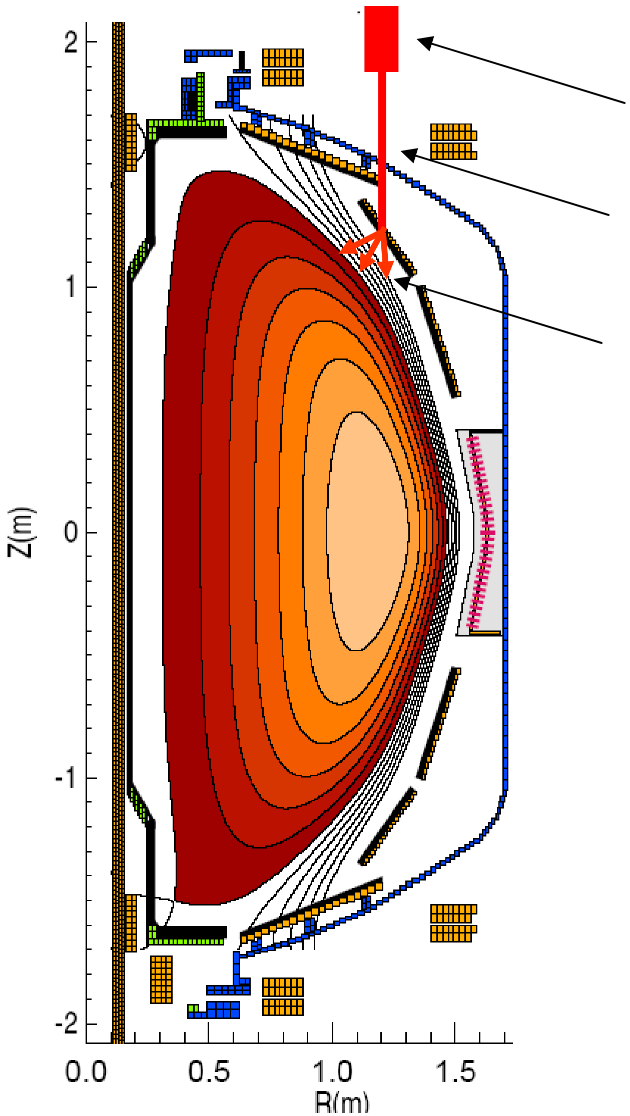
Schematic Diagram of 2008 Gravity-Based Powder Injector



Powder Repository Shaker/Dropper

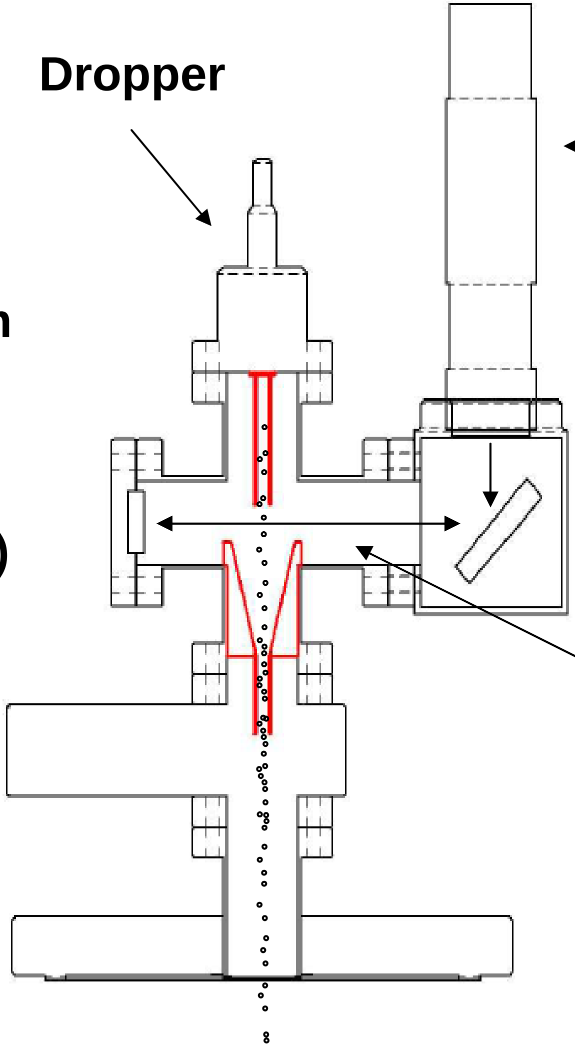
½ in O.D. Tube, 1 m long

Li Powder Dropped Slowly into SOL. Injection Spread Over Duration of the Discharge

2008 Li Powder Injection Tube Installation Geometry

The C-Mod Scattering System for Monitoring Powder Injection

The rate at which powder enters NSTX will be monitored using the laser scattering system developed and tested on C-MOD[1]. (Orthogonally viewing photodiode not shown)



J. Irby MIT

References and Acknowledgements

1. J. Irby, J. Rosati, B. Labombard, B. Lipschultze, E. Marmar, J. Rice, J. Terry, S. Wolfe, Bull. Am. Phy. Soc. 48 (2003) 100

2. Catalin M. Ticos, Zhehui Wang, Loenid A. Dorf and Glen A. Wurden, Rev. Sci. Instrum. 77 (2006) 10E304

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