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Improved NSTX Plasma Performance with Lithium Aerosol Injection

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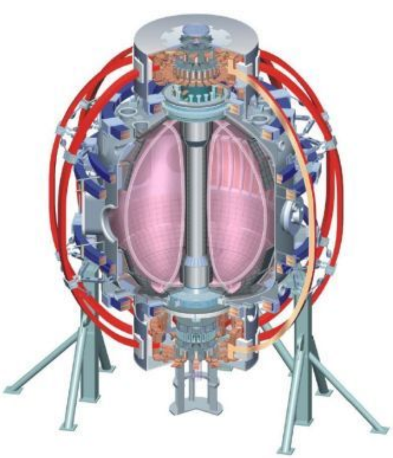

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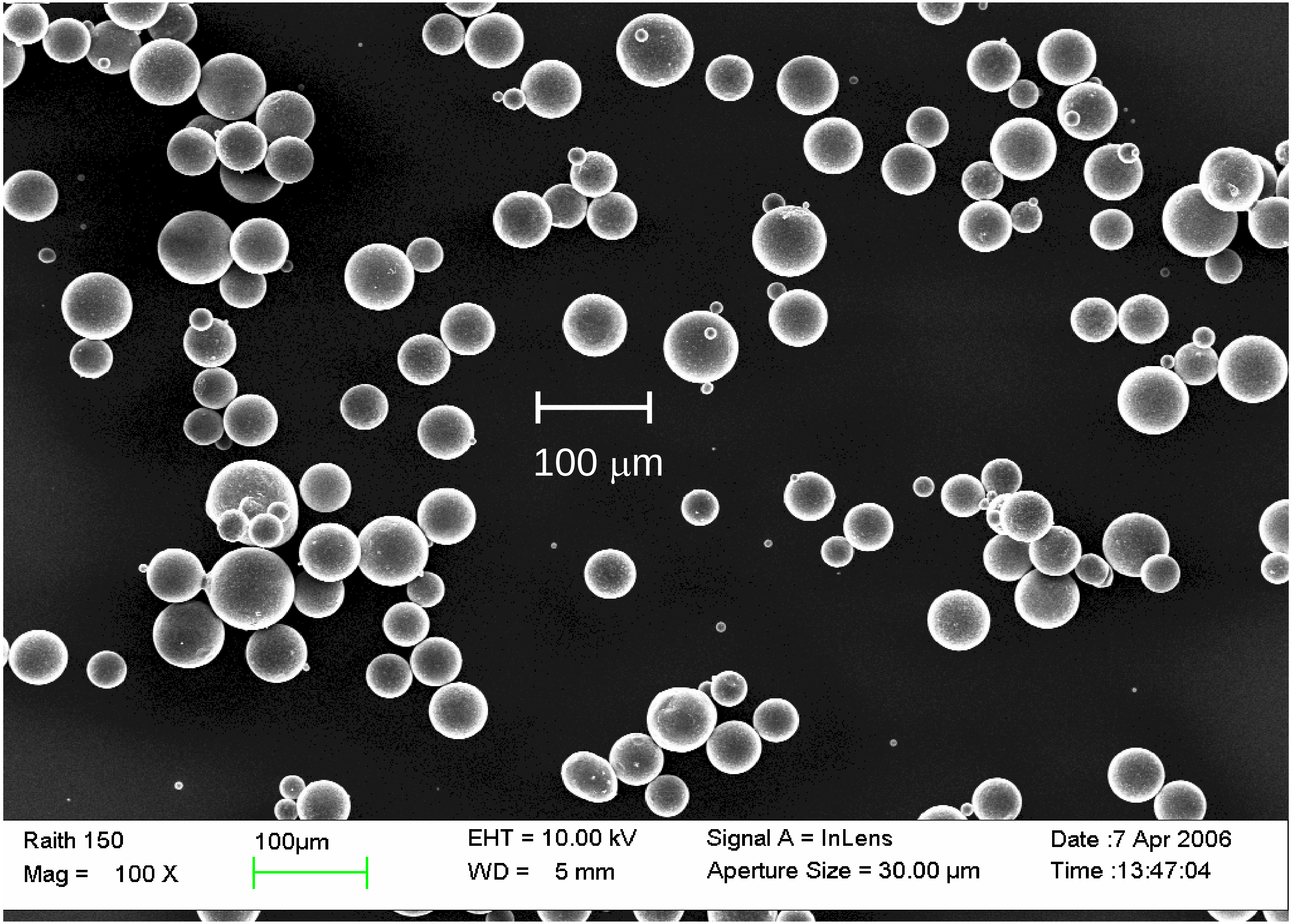
Introduction

- A simple device has been developed and used to introduce a lithium aerosol into NSTX discharges. Fluxes of ~ 1 to 35 mg/s were injected into the NSTX SOL without trauma to the NBI-heated discharges.
- Using high speed videos, individual aerosol particles have been seen to persist for tens of milliseconds in the SOL. Further, the particles have been seen to move predominantly across field lines while evaporating.
- Upon evaporation and ionization, lithium ions introduced in this scheme follow open field lines and implant into the NSTX carbon divertor surfaces where they appear to reduce recycling and frustrate the influx of impurities into the plasma core.
- The injected lithium has led to H-mode discharges with reduced Ohmic flux consumption, increased energy confinement, broader current distributions and lower central impurity accumulations as compared to discharges either without lithium or benefitting from evaporated lithium.
- These results are similar to those reported concerning aerosol injection in TFTR[1]. Further, this technique compares well with evaporation from the NSTX dual LITER system[2].

The Solid Aerosol Employed – Lithium Powder

- The lithium aerosol employed was supplied by FMC Corporation and has been trade marked as SLMP™ – Stabilized Lithium Metallic Powder™.
- Each spherical particle (average diameter ~ 44 μm) was stabilized against reaction with air by a ~ 50 nm mantle of microcrystalline lithium carbonate. The resulting particles were ~ 98.5% Li and 1.5% Li_2C0_3 by composition. A SEM image of the aerosol particles is shown in Fig 4.
- A second type of powder protected by ~ 50 nm of long chain paraffin (< 0.01% CH_2) is presently under investigation as a candidate aerosol for use on NSTX.

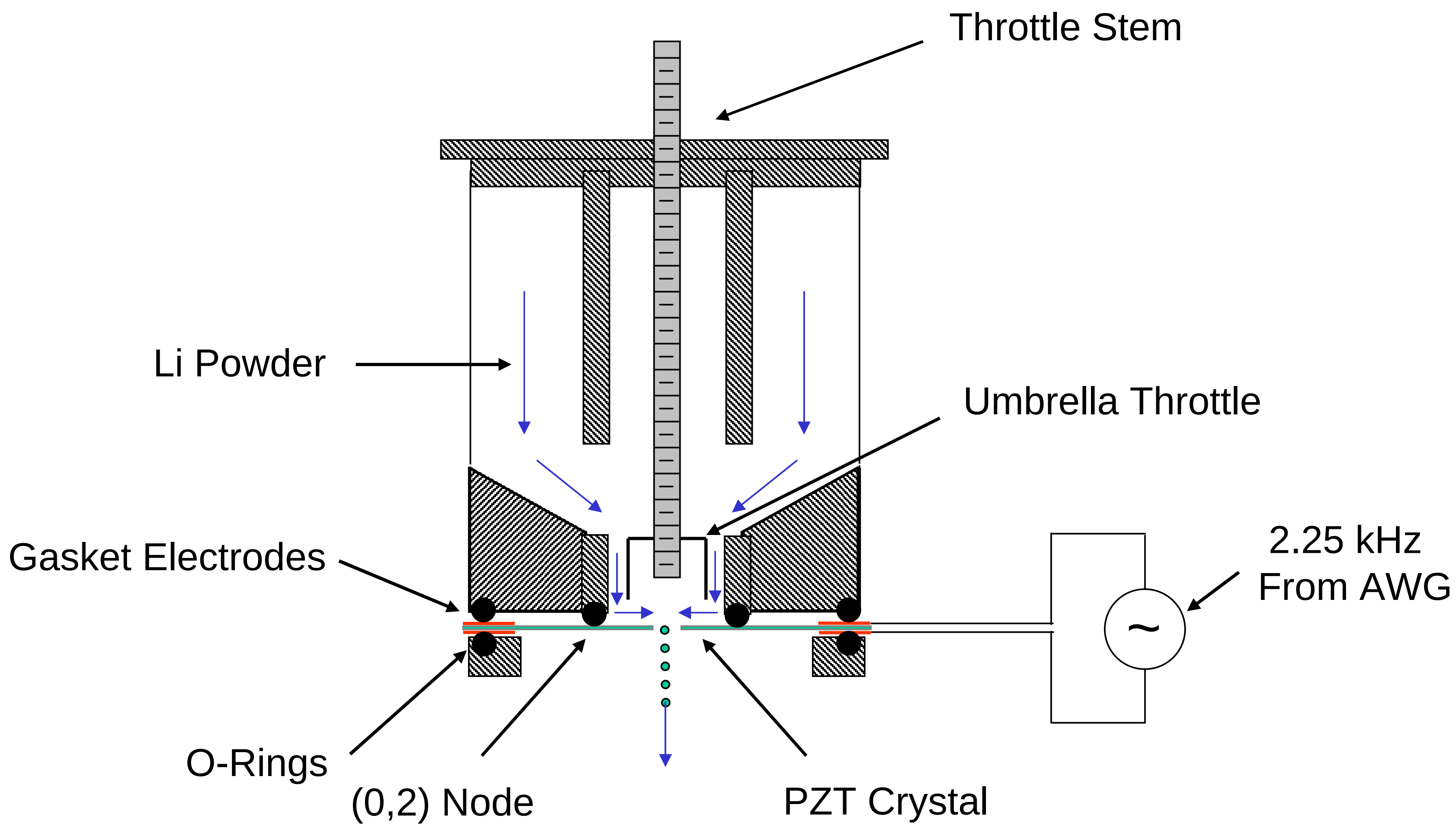
SEM Image of FMC Stabilized Metallic Lithium Powder (SLMP^{TM})



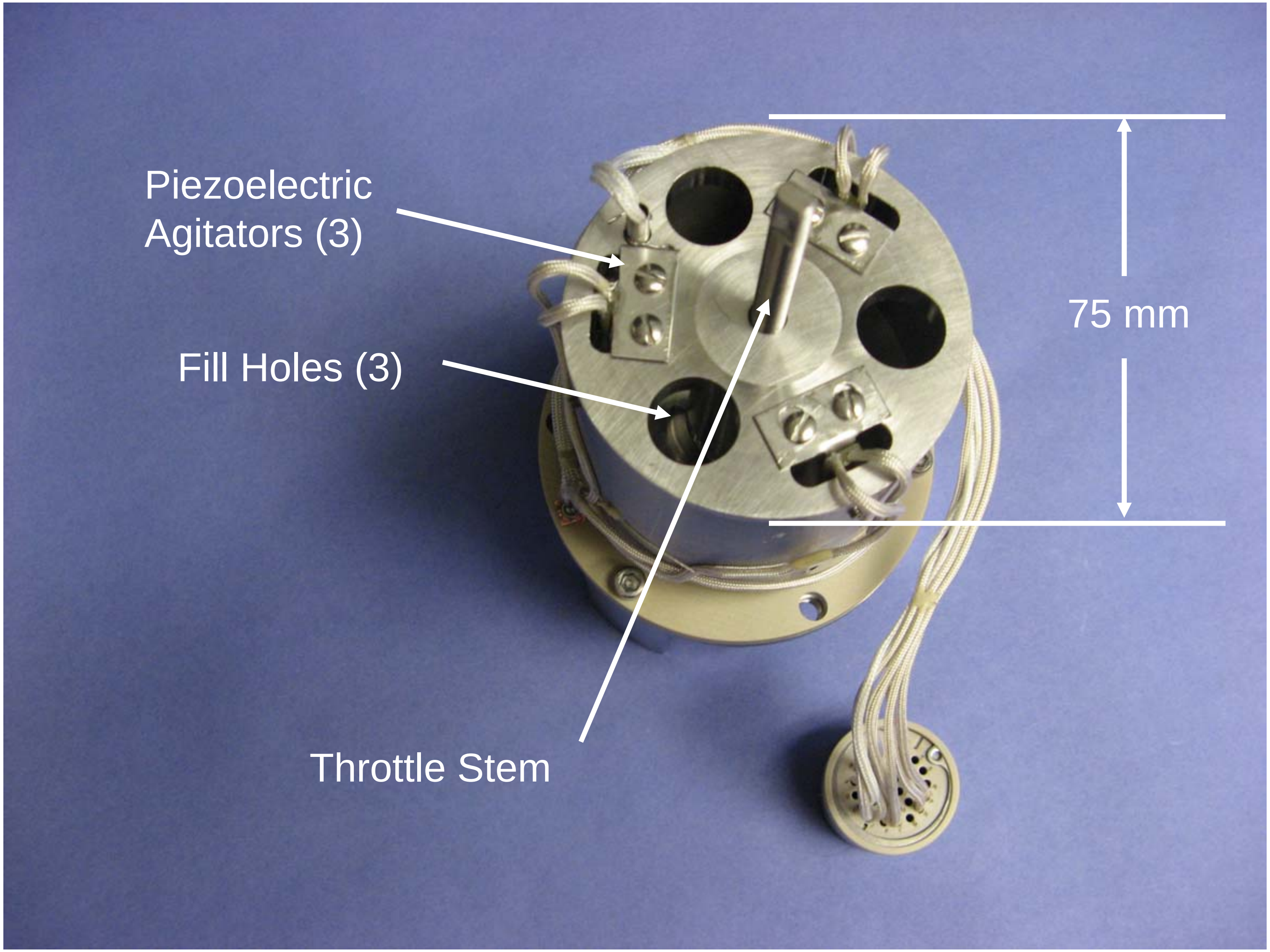
The Aerosol Injection Hardware (Dropper)

- The hardware appears in Figs 6 - 9. The heart of the device is a circular piezoelectric bending actuator with a 2.5 mm diameter hole at its center. The actuator resonates in the (0,2) drumhead mode (See Fig 8). Particles flow down onto the piezoelectric membrane from an annular reservoir located above the membrane. The particles then diffuse inward toward the hole when the membrane is driven at its resonant frequency (2.25 kHz).
- Modulation of the injected particle flux is controlled by a digital arbitrary waveform generator (AWG) which outputs a 2.25 kHz resonant signal with arbitrary amplitude modulation. Amplitudes of ~ 1 to 25 Volts were typically used to drive the piezoelectric membrane in the experiment.

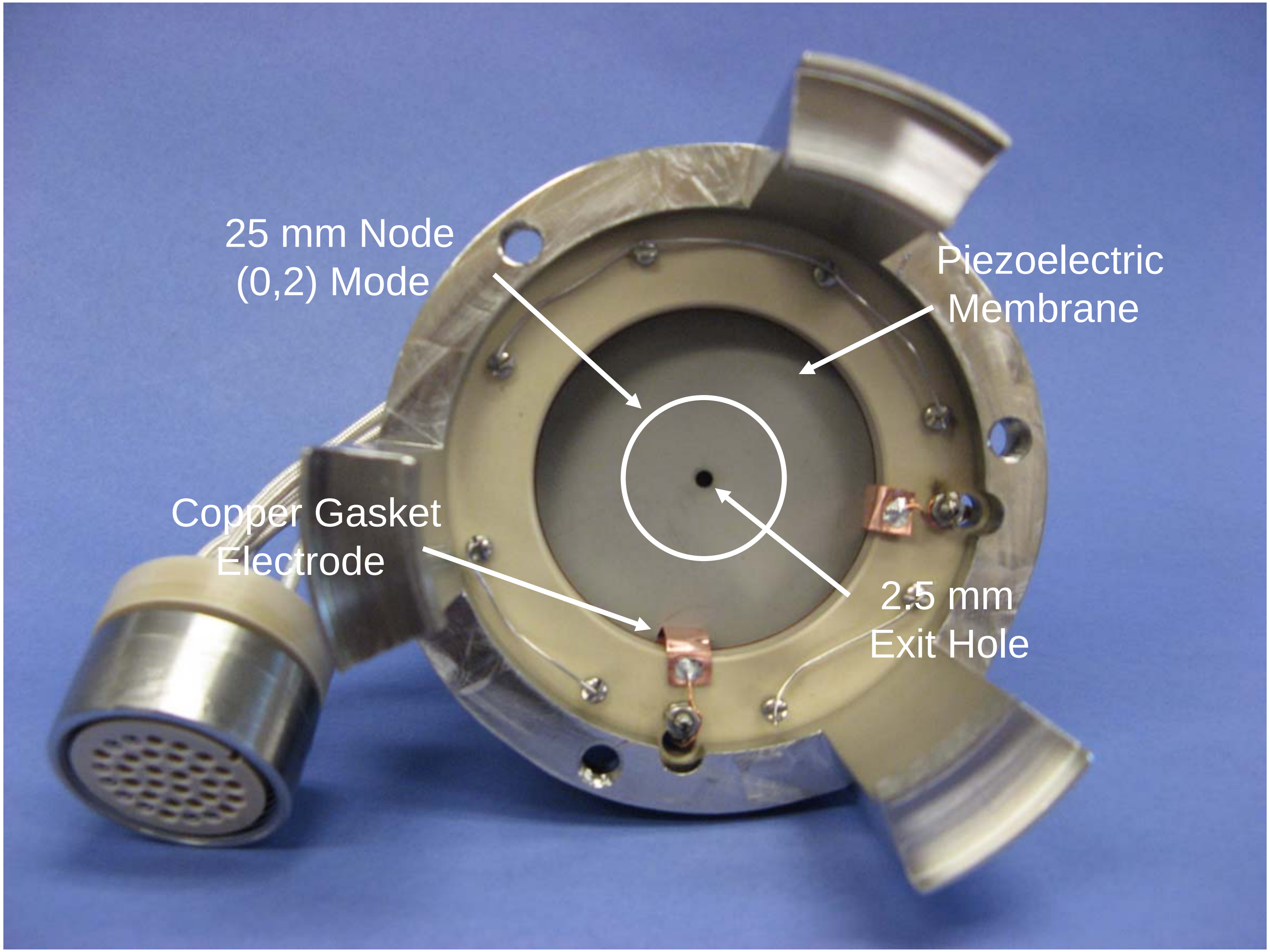
A Cut-Away View of the Injection Hardware



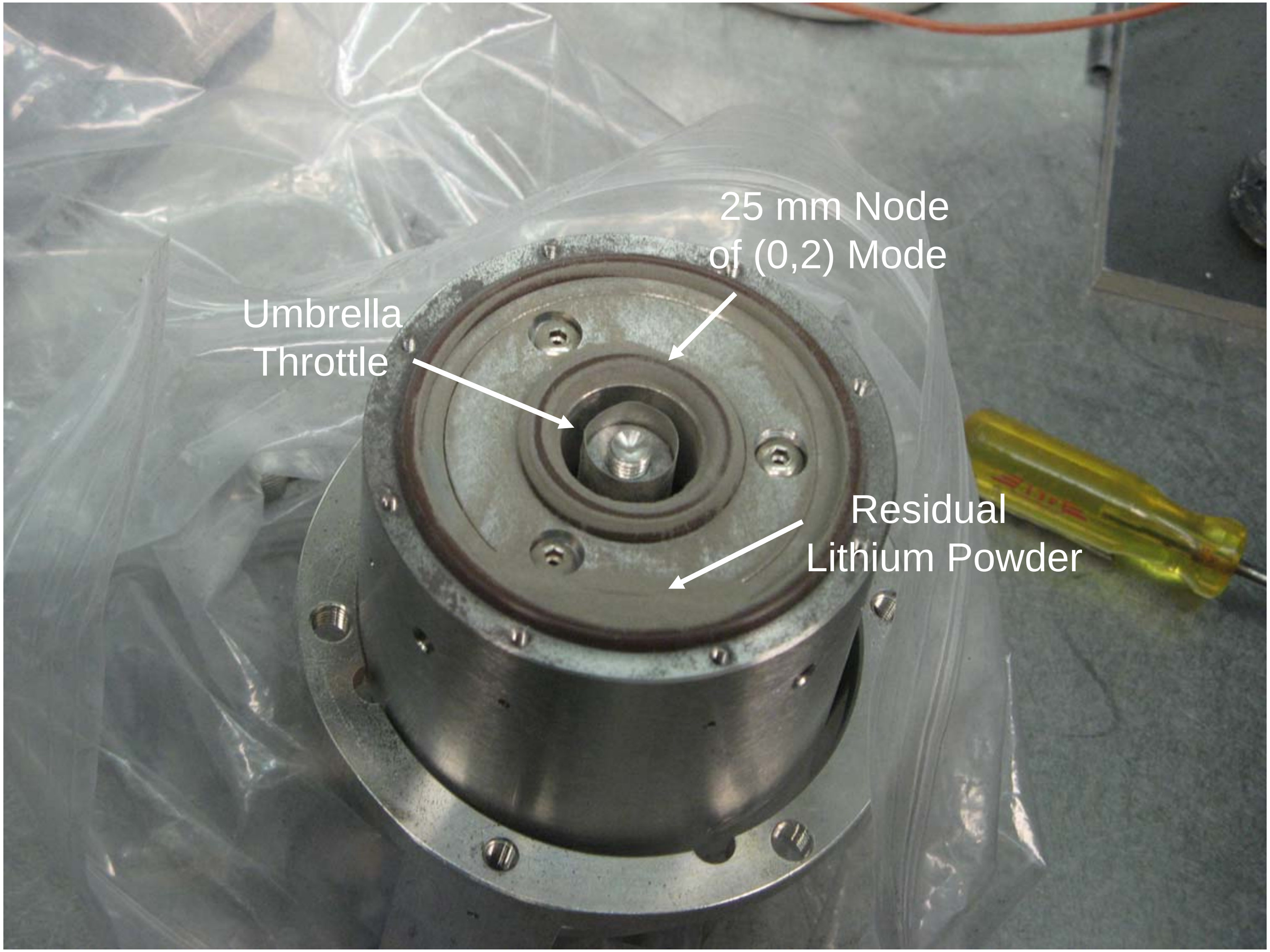
Top View of Injection Assembly



Bottom View of Injection Assembly



Bottom View of Injection Assembly with Piezo Membrane Removed



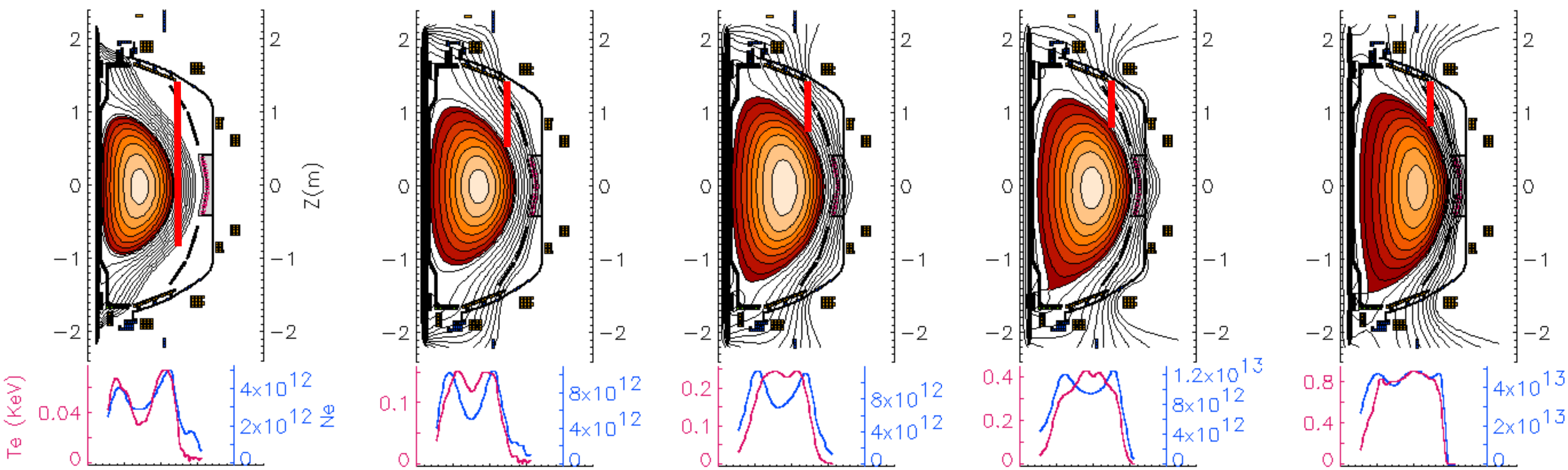
The Experiment

- Injection of lithium aerosol was accomplished successfully during 11 NSTX discharges. Various amounts, start times and temporal influx profiles were attempted.
- Plasma performance improvement was most pronounced when aerosol was introduced <u>before</u> the L-to-H transition. The timing of such aerosol injection is summarized in Fig 11 where 5 EFIT profiles are shown from 25 ms to 509 ms. Superimposed over these profiles are the trajectories of injected particles as they were dropped from a point above. As seen the aerosol did not interact with the discharge until the expanding plasma grew in major radius and “encountered” the vertical column of lithium particles at ~ 25 ms. From ~ 25 ms to ~ 80 ms the plasma was limited by the center stack before finally becoming diverted at ~ 100 ms. Transition to H-mode occurred at ~ 180 ms.
- In Fig 12, it is interesting to note the appearance of two expanding rings of Li^{+1} radiation in the neighborhood of the lower X-point at t ~ 60 ms. These rings are not presently understood.
- Individual aerosol particles can be seen in Fig 13.

Shot 130389: Early Injection of Li Powder

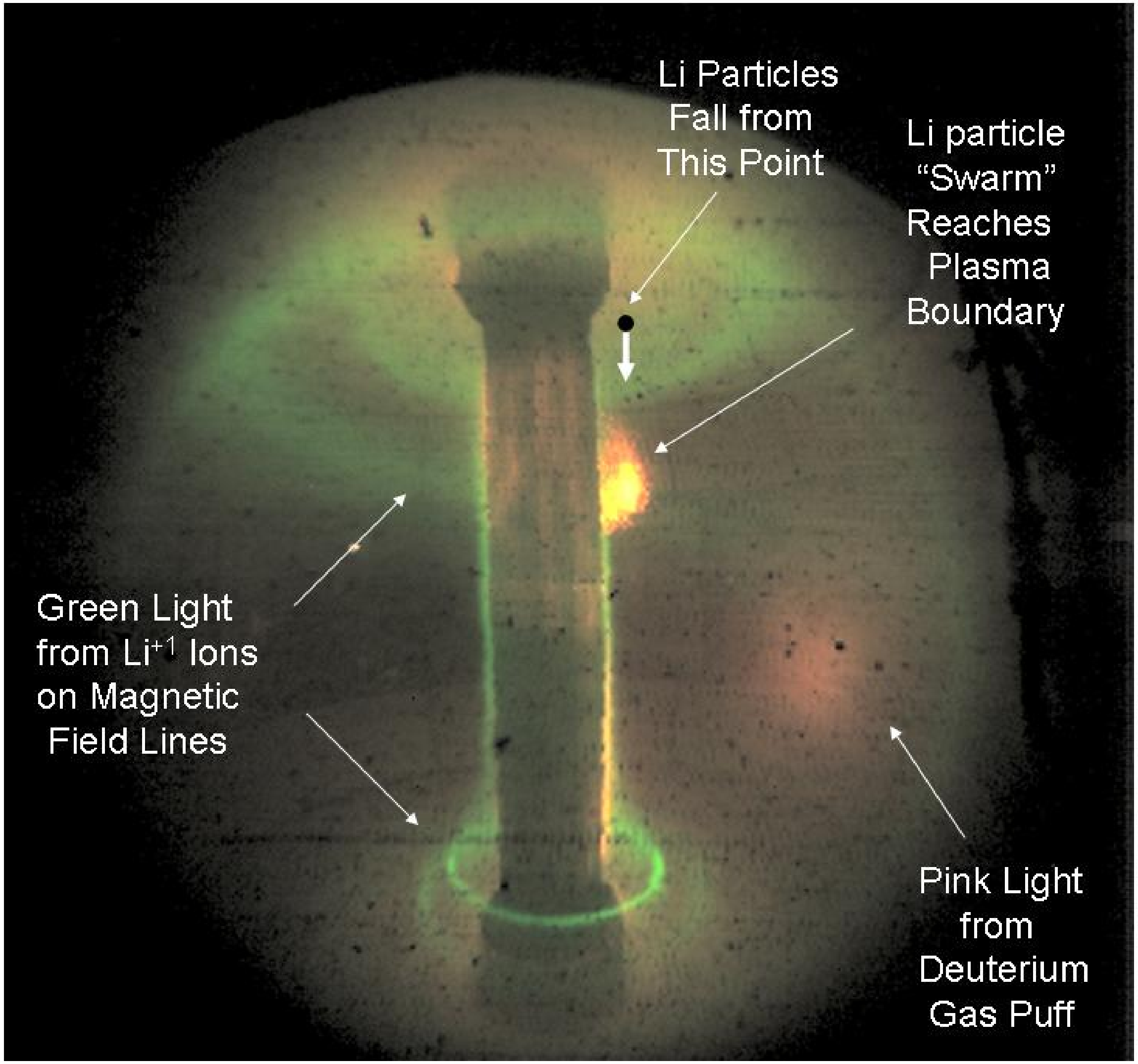
- Nominal aerosol trajectories shown by red vertical lines

Plasma Encounters Aerosol Particles	Li^{+1} Rings Observed (Fig 12)		X-Point Established (H-mode @ 180 ms)	Stored Energy Steady State



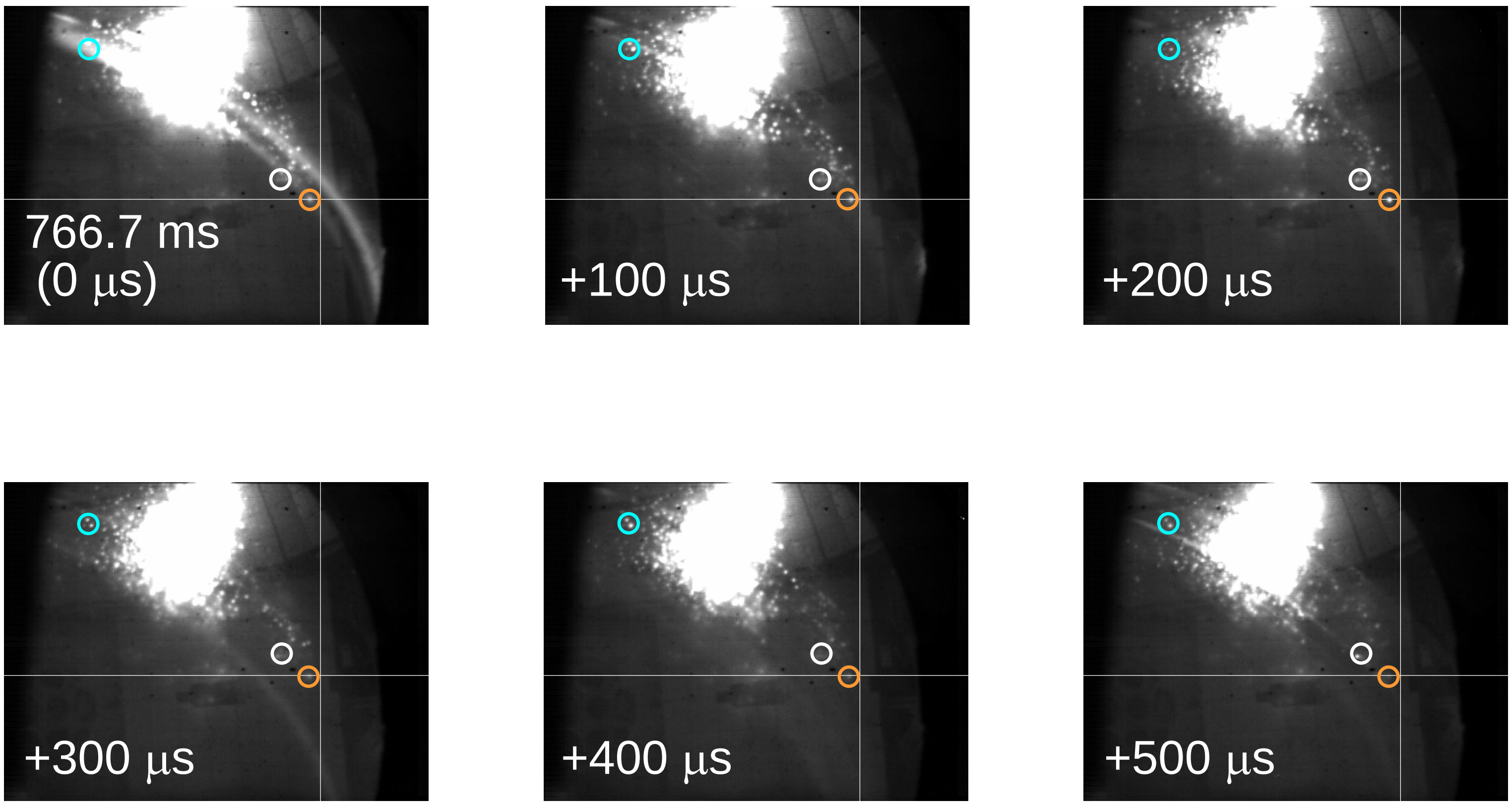
25 ms	58 ms	80 ms	102 ms	509 ms

Camera View of Early Li Aerosol Injection Taken at t ~ 60 ms



10 kHz Images of Individual Aerosol Particles

- Individual particle “twinkling” and interaction with filaments apparent (see circles)
- Particle size and composition can be pre-determined for dust studies
- Trajectories for dust studies have been obtained using two cameras simultaneously

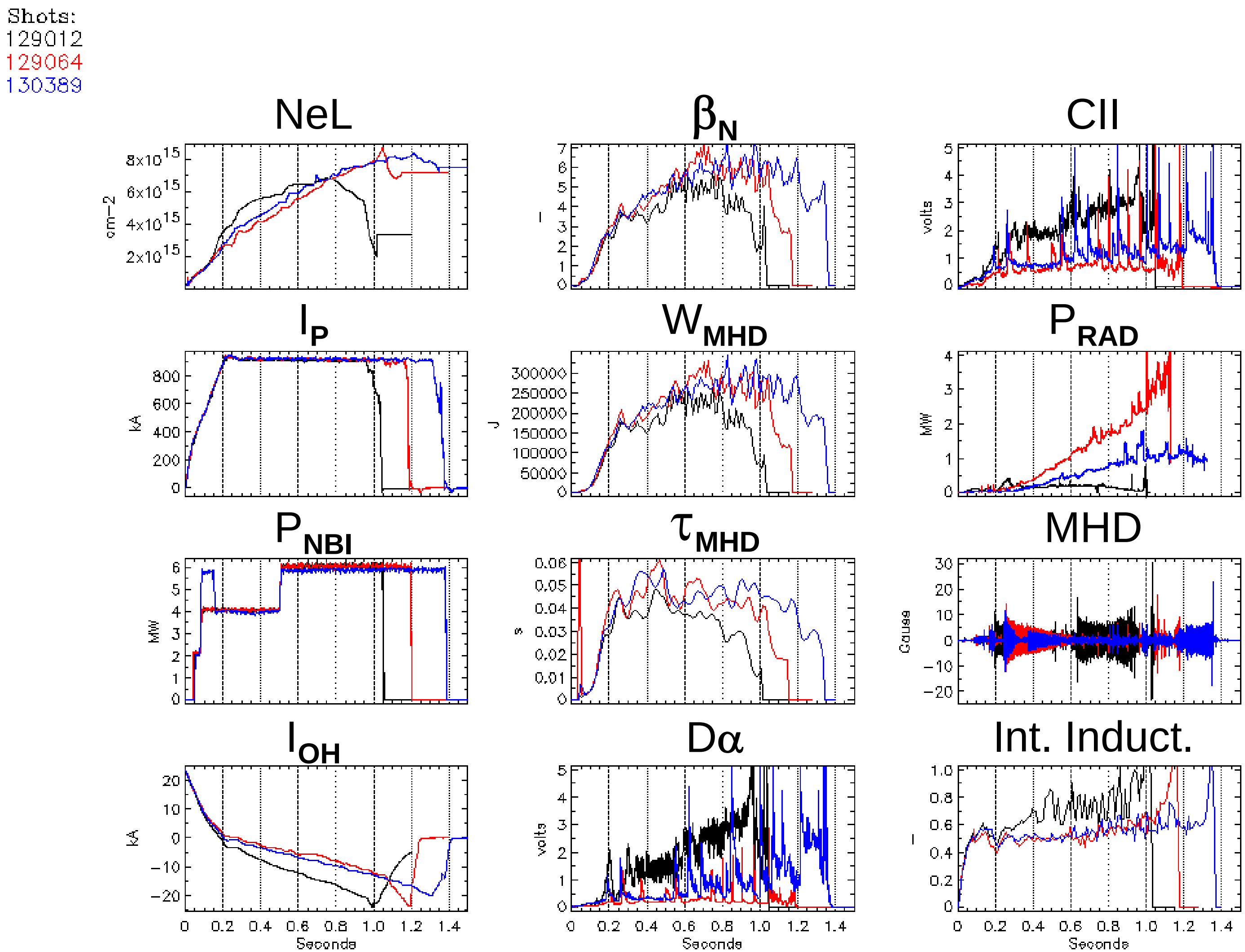


Physics Results

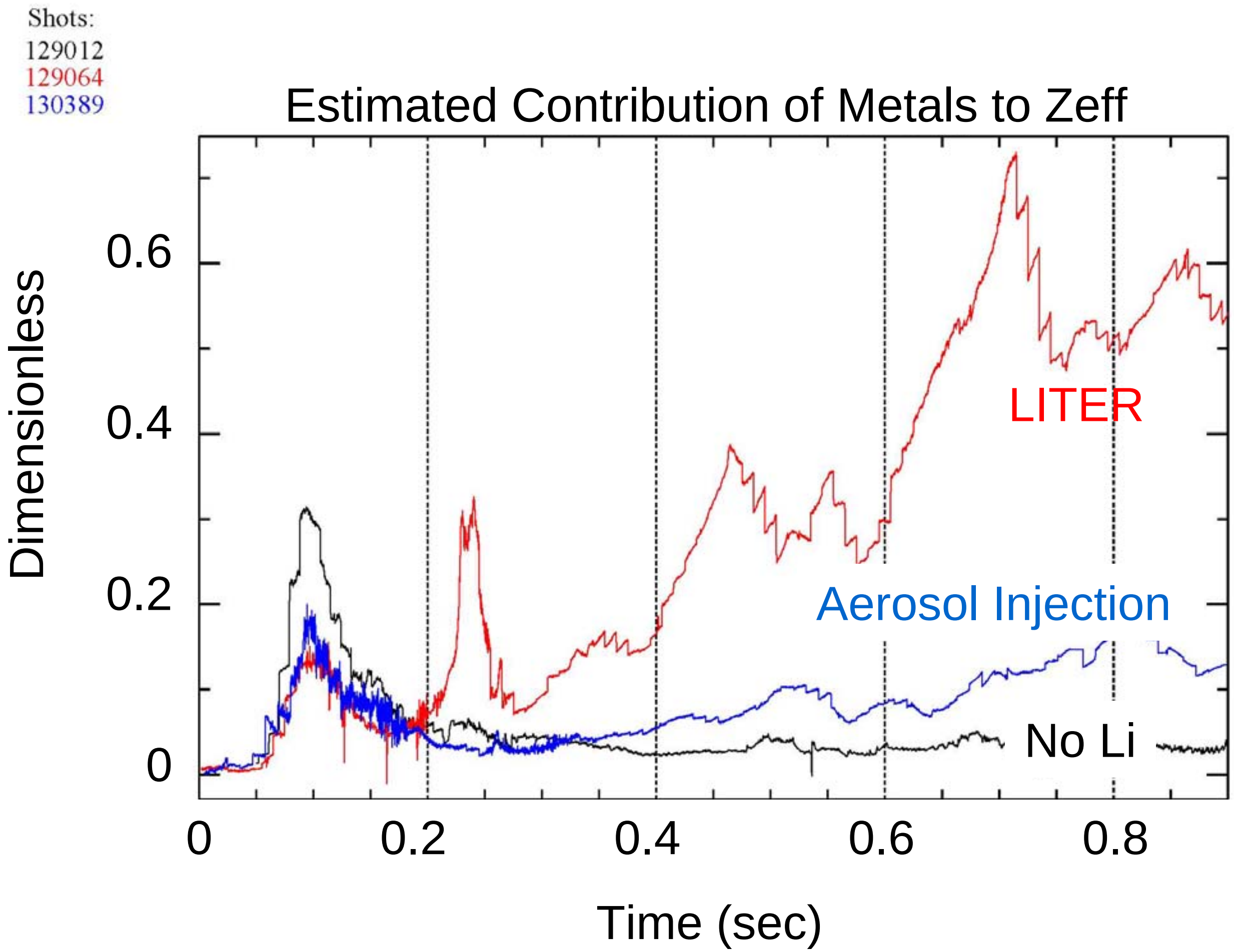
- Several performance improvements were observed as a consequence of lithium aerosol injection as compared to discharges with either no lithium or many 100's of milligrams of lithium evaporated into the lower divertor using the dual LITER system. In particular the following features can be seen in Fig 15:
  - As compared to no-lithium discharges
    - Lower OH consumption
    - Higher Stored Energy
    - Reduced Recycling
    - ELM Suppression
  - As compared to discharges with several hundreds of milligrams of lithium evaporated just prior to break-down using the Dual LITER system
    - Reduced Impurity Accumulation (also Fig 16)
    - Extremely "flat" ne and Te profiles (Figs 17 and 18)

Comparison: LITER, Aerosol and No Lithium Shots

No Li   700 mg LITER   7 mg Early Li Aerosol



Comparison: Zeff(0) from Metals
No Li 700 mg LITER 7mg Early Li Aerosol



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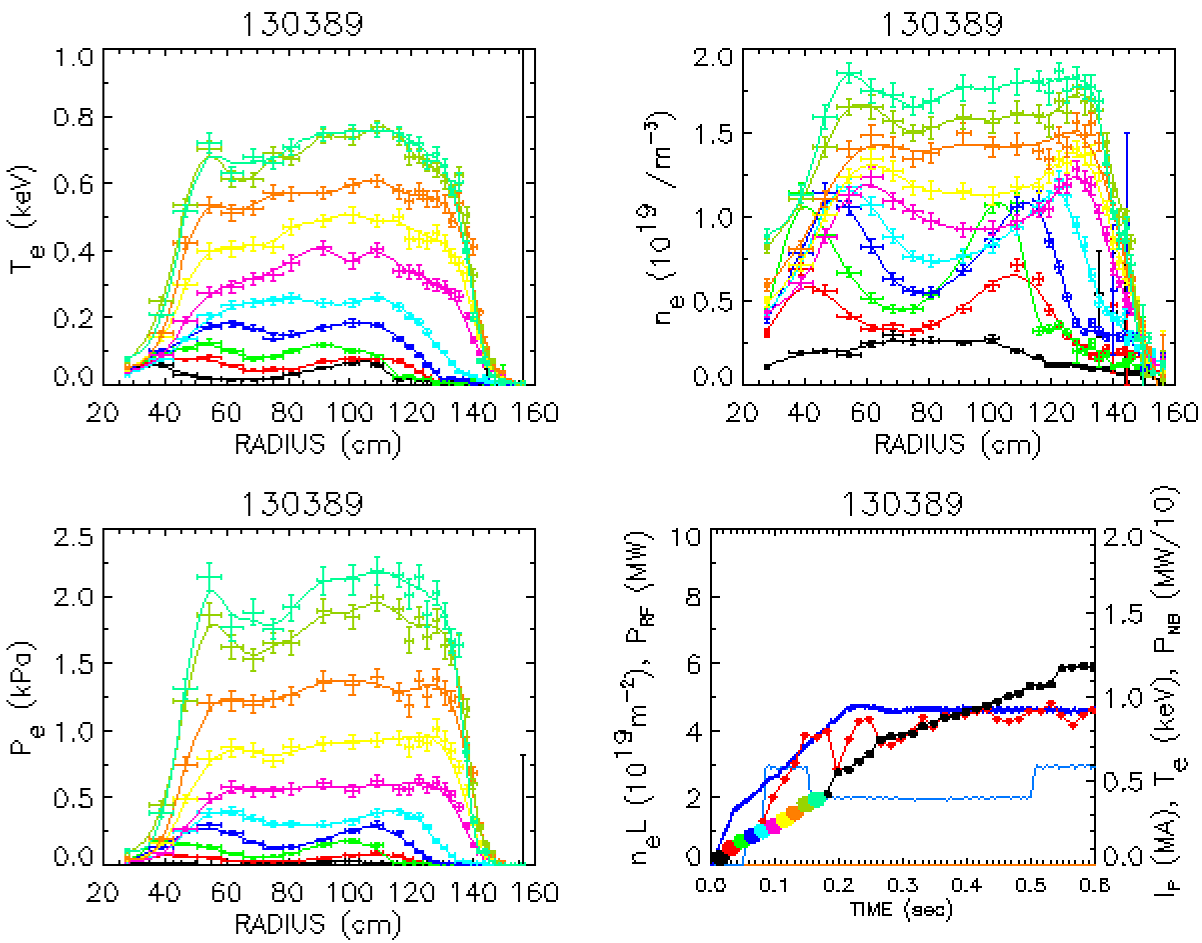
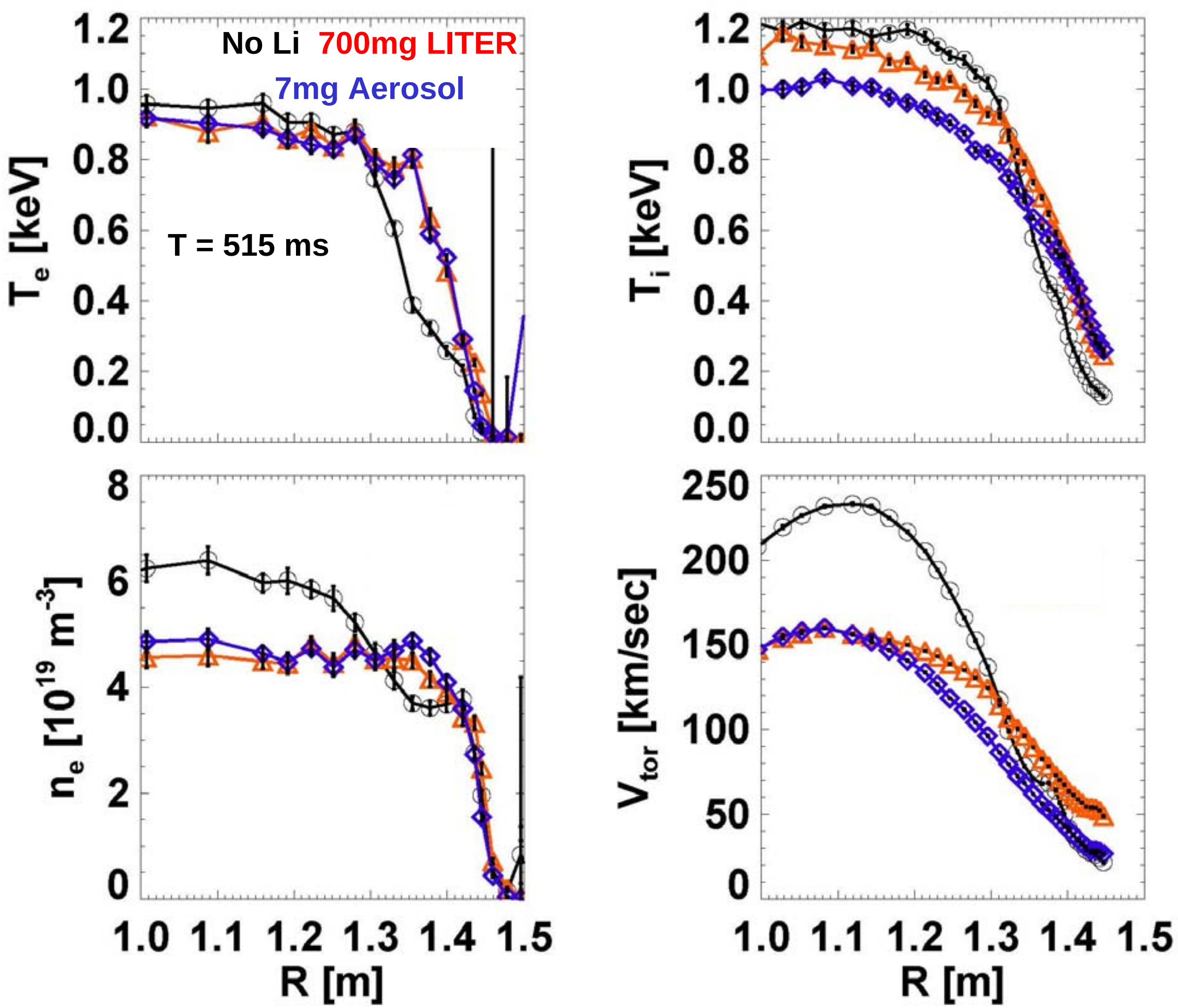
Early Lithium Injection: “Flat” n_e, T_e and P_e Profiles

• Continuous Aerosol Injection Starting Before Plasma Breakdown



7 mg Li Powder: Nearly Same Effect as 700 mg LITER Plasma Steady State (t ~ 400 – 700 ms)

- Plasma Parameters @ 515 ms - shot 130389



Future Plans – 2009 Run

- Future plans include design changes aimed to improve reliability of the injector hardware as well as adding a second dropper system.
- Because injection before L-to-H transition seems encouraging, aerosol injection before plasma breakdown will be attempted in 2009. Further, particle re-direction toward the center stack so as to make lithium available to the plasma earlier than would be possible with simple vertical injection (i.e. $t < 25$ ms - Fig 11) will also be pursued.
- In principle, the injector hardware can be employed to inject small amounts of any solid granular material and hence could perhaps be useful for dust studies (Fig 13).
- It is also possible that the dropper could be used to re-supply the Liquid Lithium Divertor scheduled for installation in NSTX in 2009.

References and Acknowledgements

- References:

1. D. K. Mansfield, *et al*., Nucl. Fusion **41** (2001) 1823

2. H. Kugel *et al*, Phys. Plasmas **15** (2008) 56118

- Acknowledgements:

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