Effects of Large Area Liquid Lithium Limiters on Spherical Torus Plasmas

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Motivation for liquid lithium wall experiments

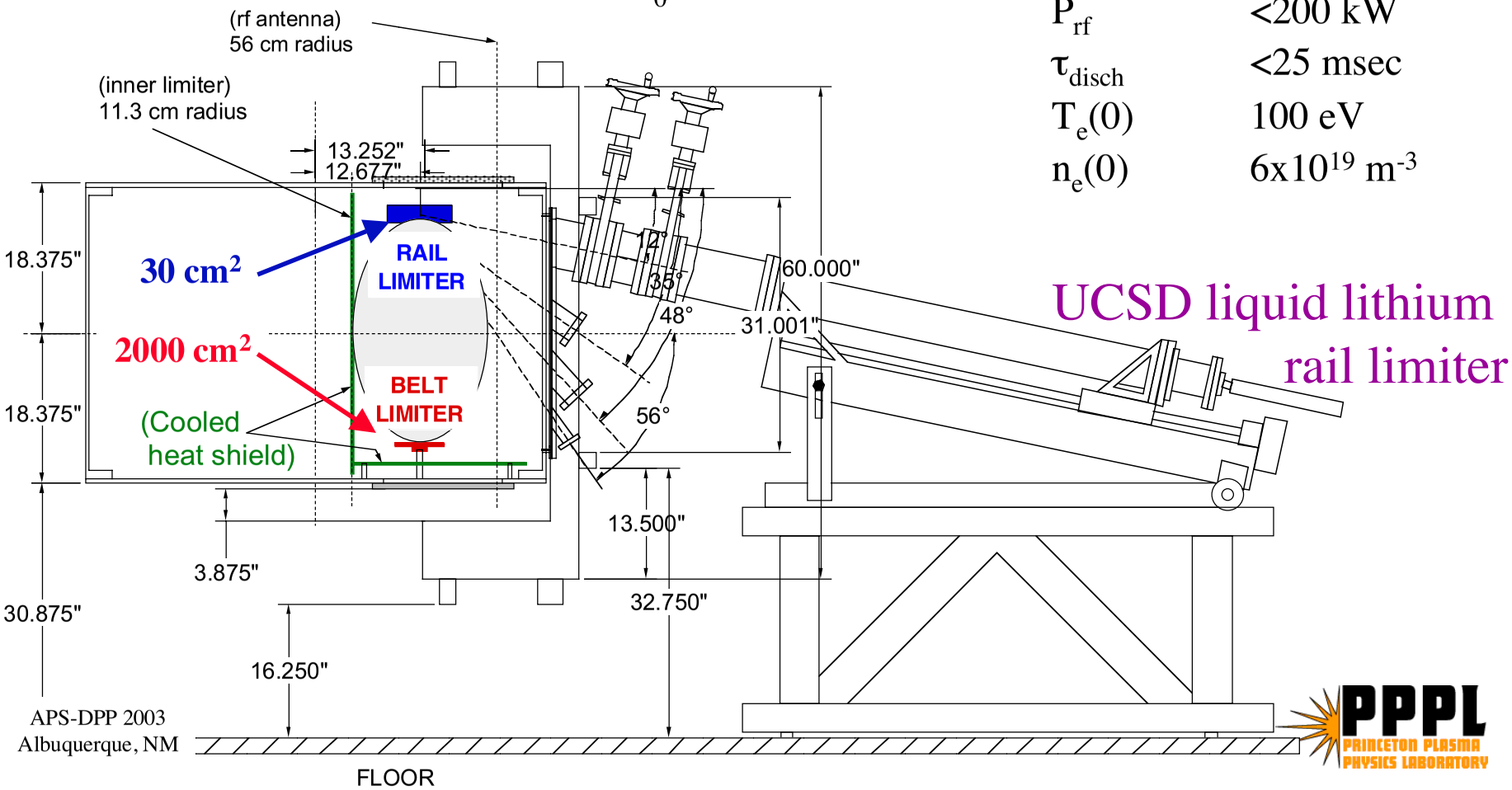
- Liquid metals are a potentially *revolutionary* solution to the 30-year old materials problem in a fusion reactor, simultaneously providing:
  - Elimination of erosion concerns - the wall is continuously renewed
  - Substantial reduction in activated waste
  - High heat handling - allowable power densities may exceed 25 MW/m^2
- Liquid lithium first wall/divertor may also provide significant *physics* advantages:
  - Novel confinement regimes with very low recycling walls
    - » Elimination of electron conduction losses
  - Stabilization of resistive MHD modes in the presence of a fast flowing (10 - 20 m/sec), close fitting, conducting wall
  - Control of the density profile through fueling

CDX-U focuses on technology of liquid lithium use in ST's and plasma interactions with liquid lithium PFC's

⇨Not simultaneously installed

R_0	34 cm
a	22 cm
$A=R_0/a$	≥1.5

κ	≤1.6
$B_T(0)$	2.2 kG
I_P	≤ 80 kA
P_{rf}	<200 kW
τ_{disch}	<25 msec
$T_e(0)$	100 eV
$n_e(0)$	6×10^{19} m^{-3}



UCSD liquid lithium rail limiter

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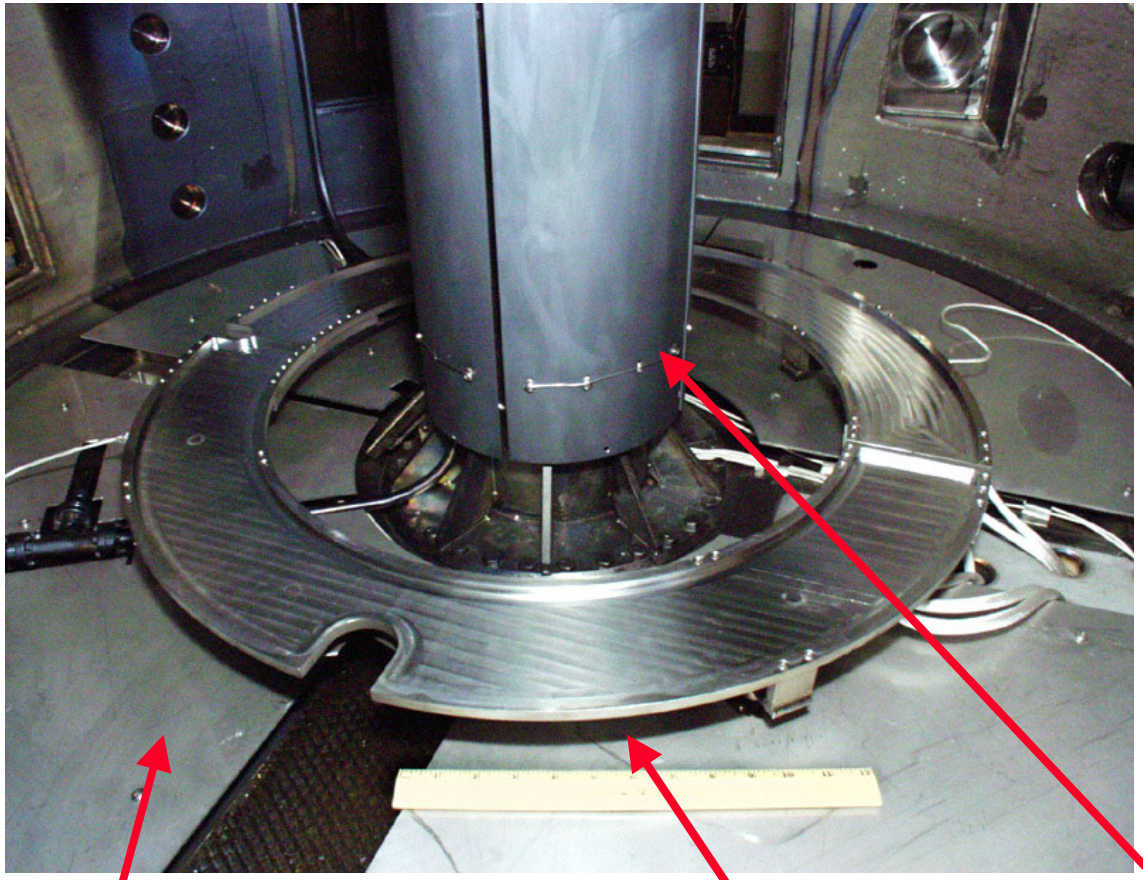
CDX-U tray limiter enables first test of large area liquid lithium limiter in toroidal confinement device



- Discharges run on bare SS tray to establish baseline prior to lithium filling

- 34 cm major radius, 10 cm wide, 0.64 cm deep

- Fabricated in two halves with a toroidal electrical break
  - -Isolated from vessel
  - -Halves connected to electrical feedthroughs

- Heaters beneath for temperature control up to 500°C.

- Heat shield on center stack

- Heat/lithium shield between tray and lower vacuum flange

- Tray temperature monitored with thermocouples around edge

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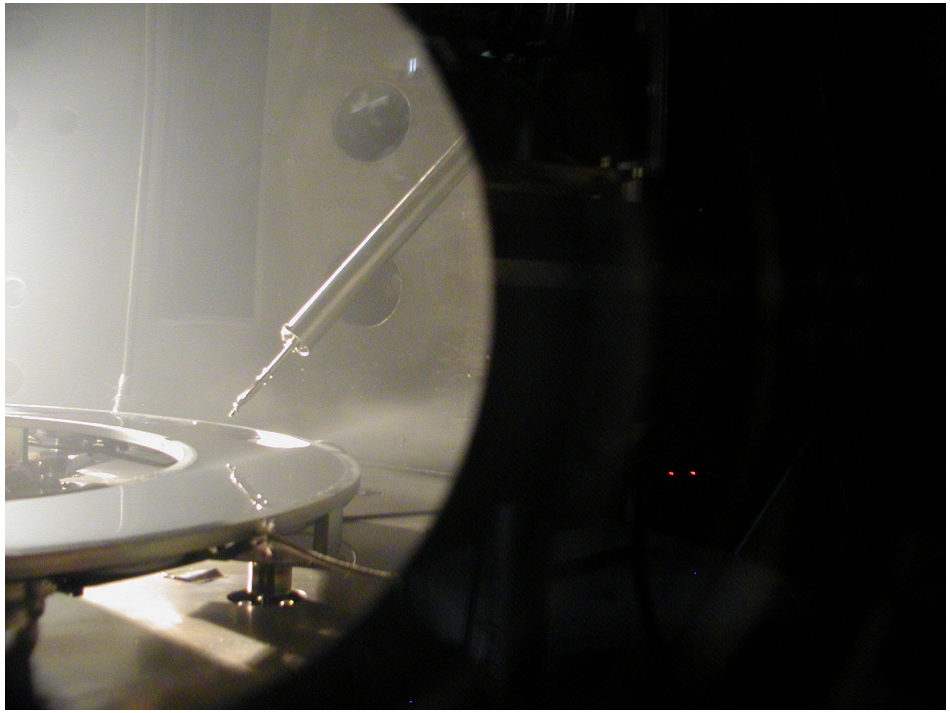
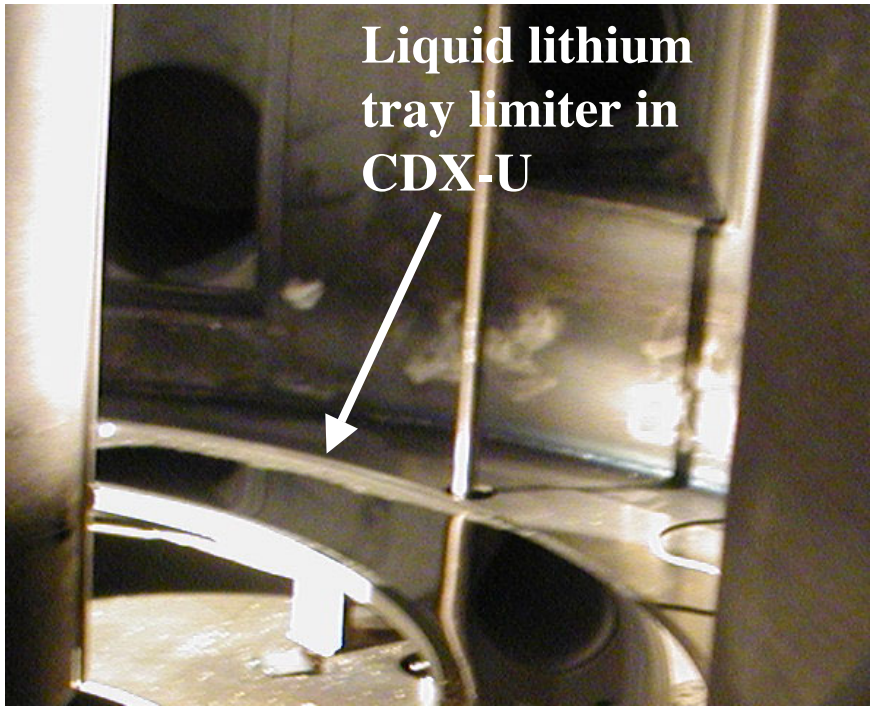
CDX-U began experiments with toroidal liquid lithium limiter in May 2003

- New filling technique (UCSD)
  - Load liquid lithium onto 500°C tray
  - Tray coverage ~80%
- Only thin coatings appear between runs
  - Removed by argon glow, heating
- **NO** mobilization of the lithium in initial experiments



Injector and tray immediately after fill



Tray after ~40 discharges.

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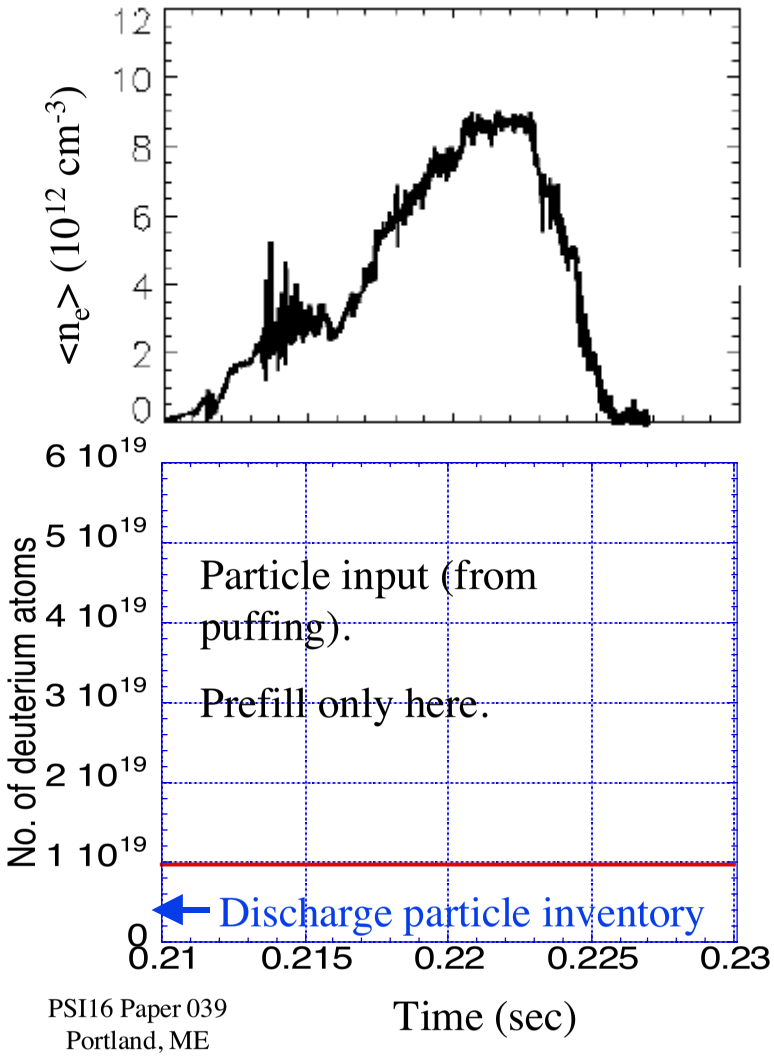
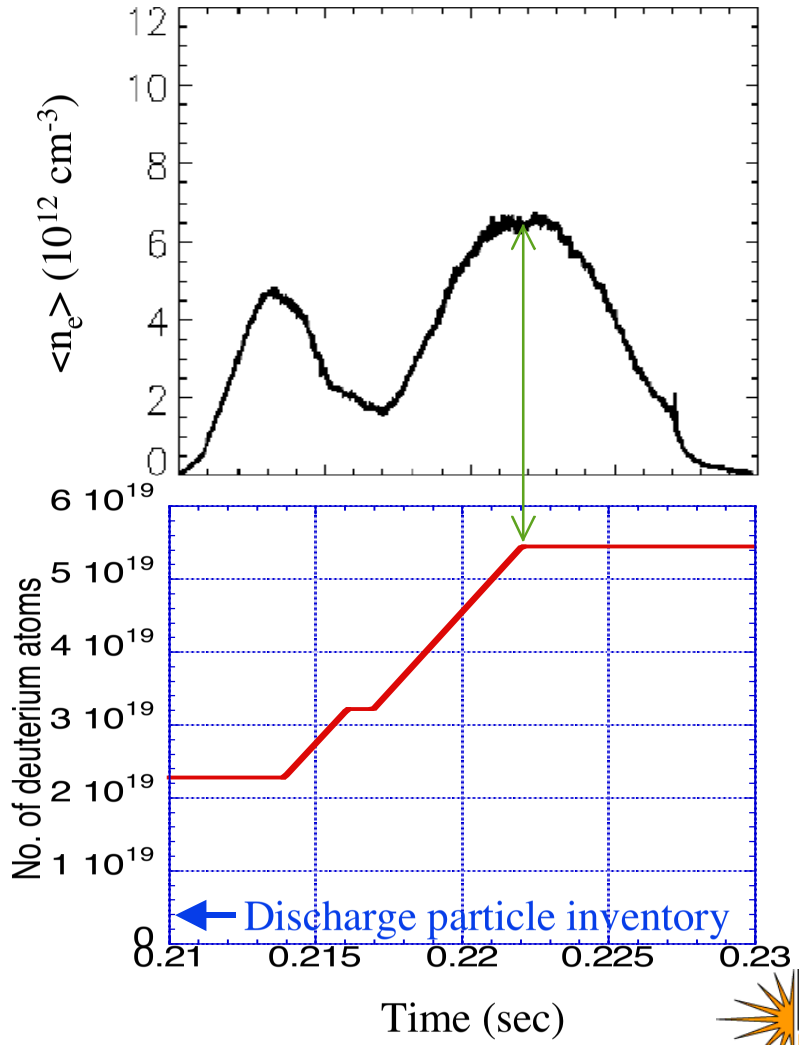
Clear effect on plasma fueling characteristics observed with liquid lithium limiter

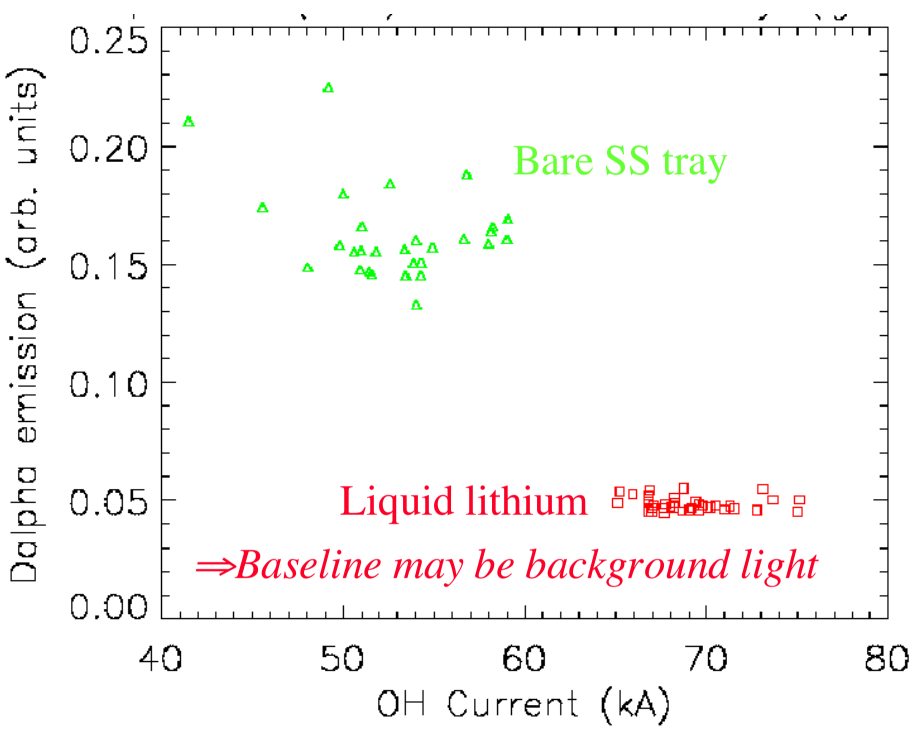
- Liquid lithium limiter increases fueling requirement by 5-8 ×.
- Density begins to pump out within ~1msec of cessation of puffing.

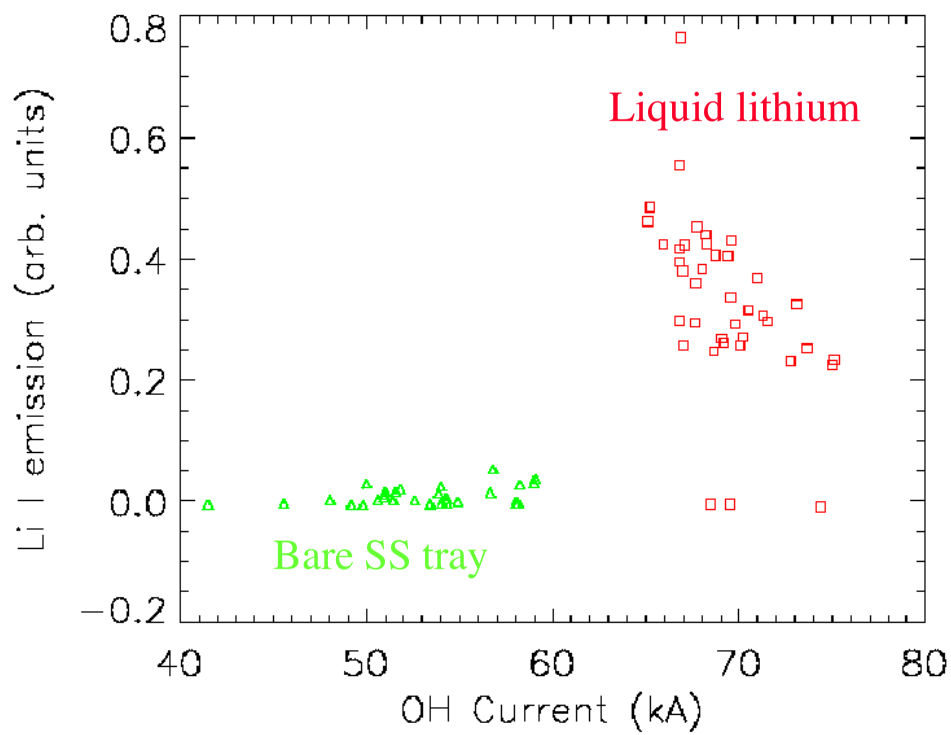




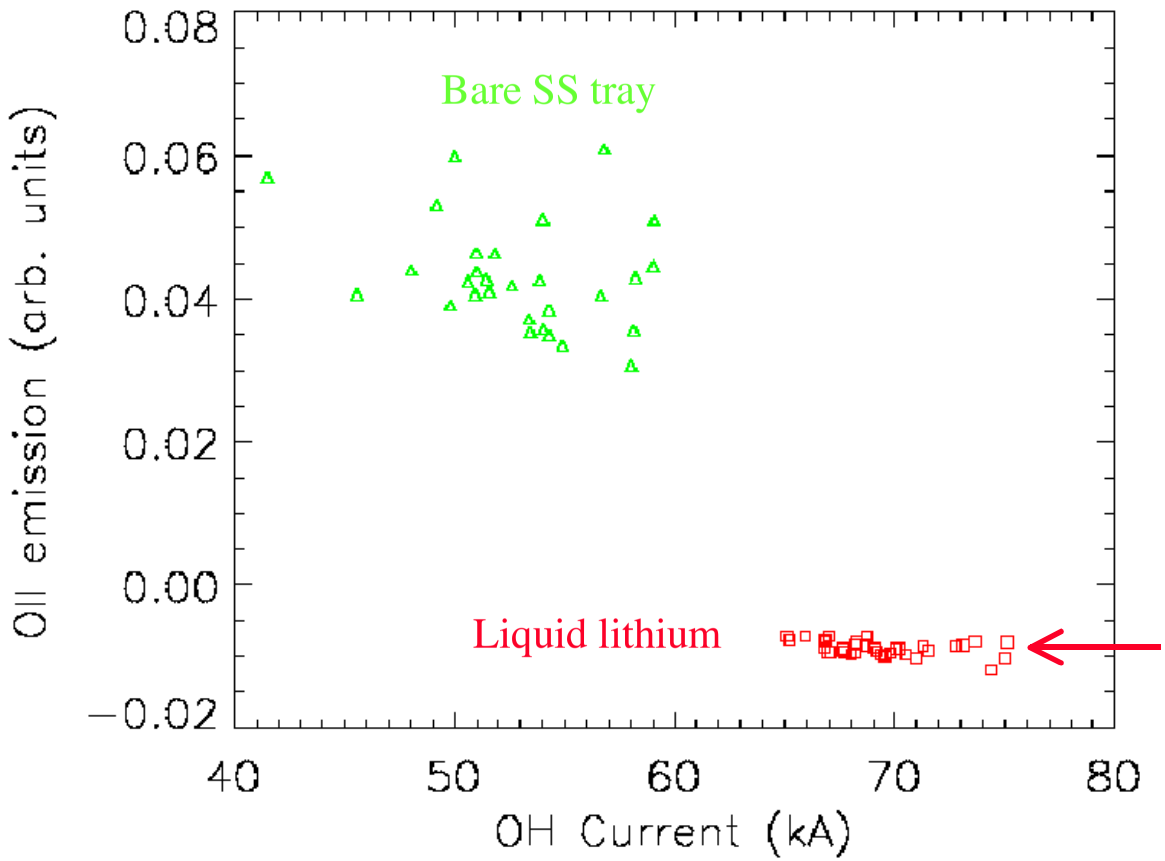
Global recycling reduced with liquid lithium limiter

- Filterscope viewing centerstack show changes with lithium limiter
  - Indicative of global D_α
- Strong lithium emissions in centerstack view probably due to coatings
  - Evaporation from liquid lithium tray create solid coating on centerstack





Oxygen is strongly reduced



Oxygen emission at centerstack is zero: displacement due to digitizer offset

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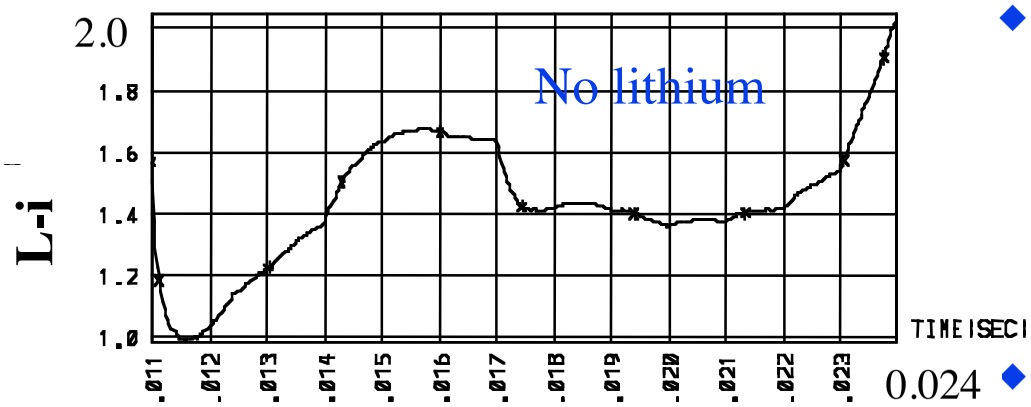
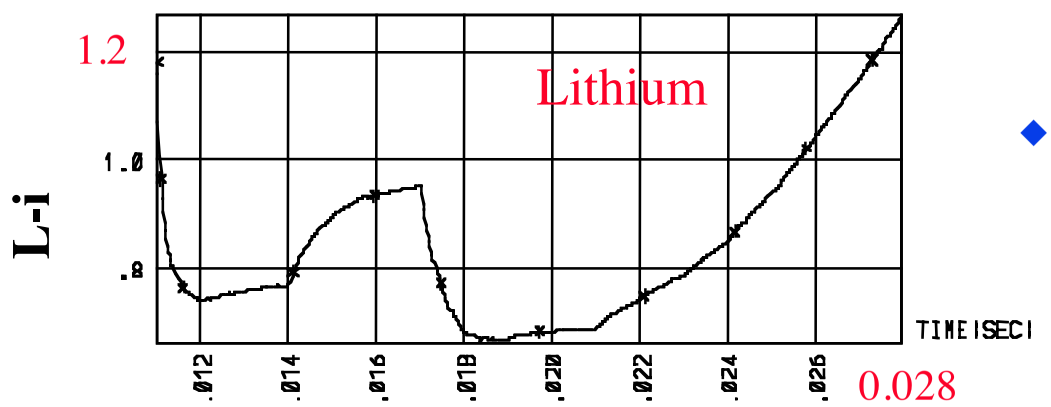
TSC simulations of plasmas after first liquid lithium limiter fill suggest broadened current channel





- Characteristics of liquid lithium limited discharges:
  - Low loop voltage
  - Robust nature of discharges
    - » Endured negative loop voltage for several msec
- TSC modeling indicated large difference in plasma internal inductances
  - L_i for lithium discharges ~2× lower
- This result is primary motivation for continued tray experiments
  - May confirm primary prediction of Krasheninnikov and Zakharov for lithium tokamaks

S. Jardin

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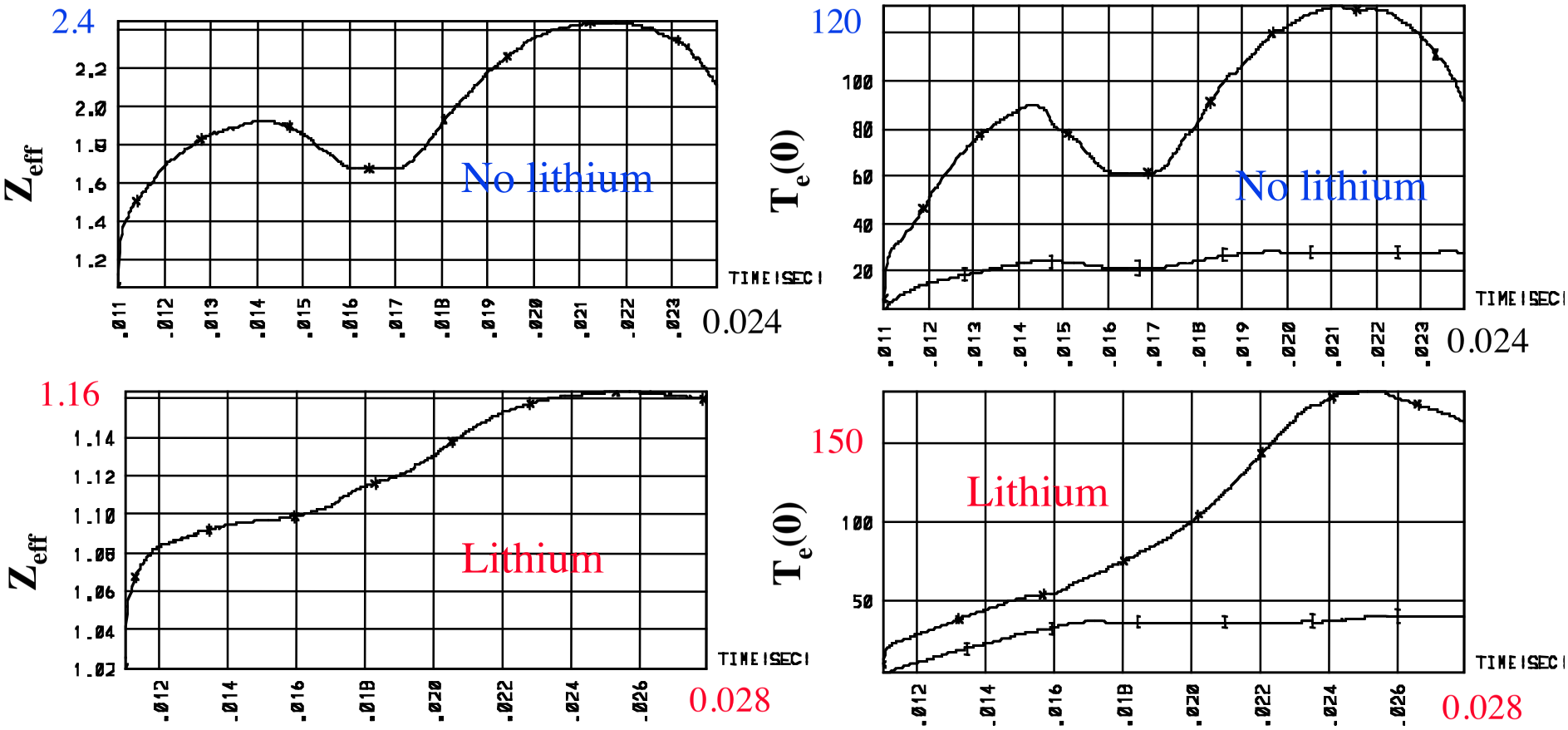
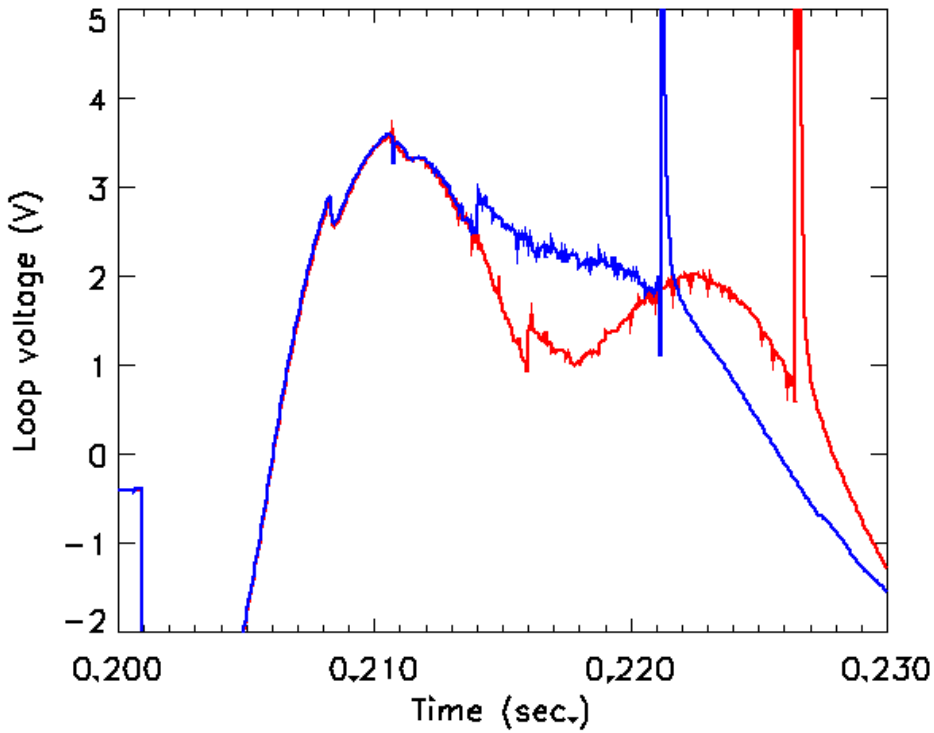
TSC simulations of plasmas after first liquid lithium limiter fill also indicate very low Z_{eff}

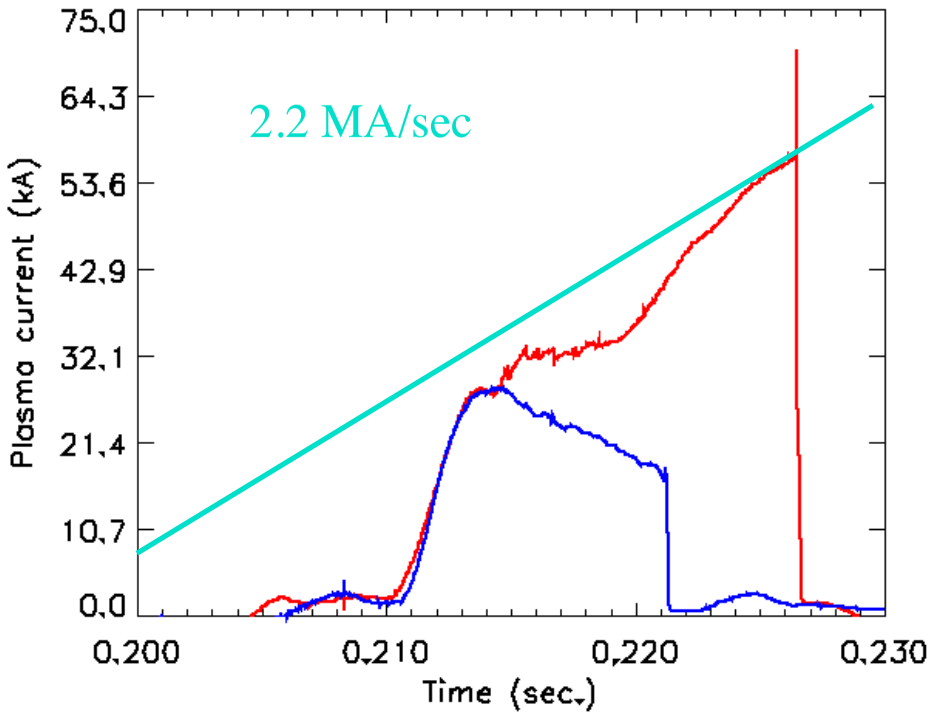


- Soft x-ray emission support peak temperature (with lithium) of not more than ~150 eV
  - Used to constrain TSC modeling
- Observed plasma resistivity with lithium limiter requires very low Z_{eff}

Shots after April 2004 lithium fill show significant improvement in efficient loop voltage utilization

- Current ramps at 2.2 MA/sec with $V_{loop} < 1$ V
- Indicates broad current channel, very low Z_{eff}
- *Very* desirable for larger spherical torus experiments like NSTX
- Small tokamaks have never previously operated at such low loop voltage





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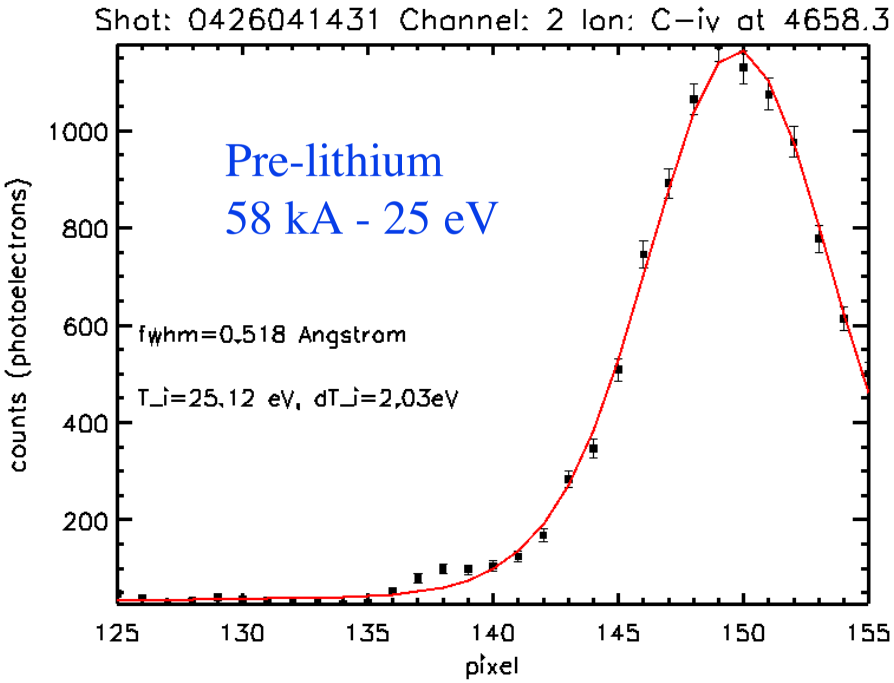
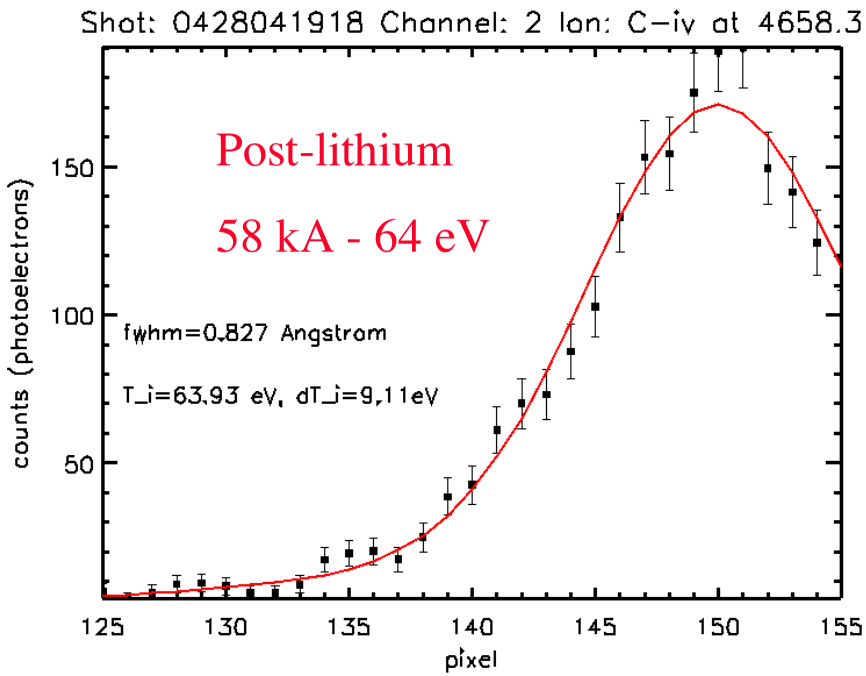
Shots following latest lithium fill exhibit a factor of 2-3 increase in ion temperature

- Ion temperature determined spectroscopically from CIV line broadening show increase after limiter tray lithium fill

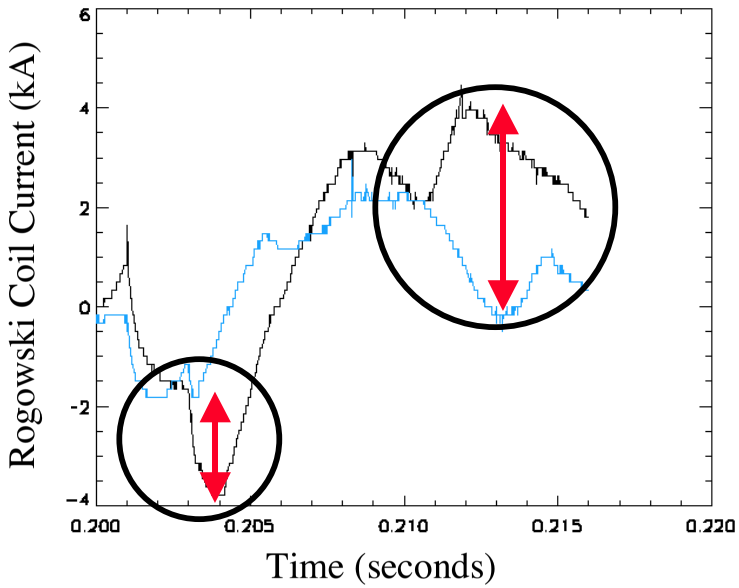




"Thermomechanical" lithium flow caused "short" and lithium expulsion from toroidal limiter tray

- Coating developed on interferometer window on first day of latest fill
- Removal attempted with prolonged argon glow discharge cleaning (GC)
  - 26 hours with tray as electrode
  - Approximates 13 run days that each begin with 2 hours of GDC
- Lithium migrated over tray edge and shorted toroidal gap
  - Induced toroidal current can cause substantial jxB force on lithium
- Solution:
  - Remove heaters at tray edges
  - Plasma-spray edges with tungsten

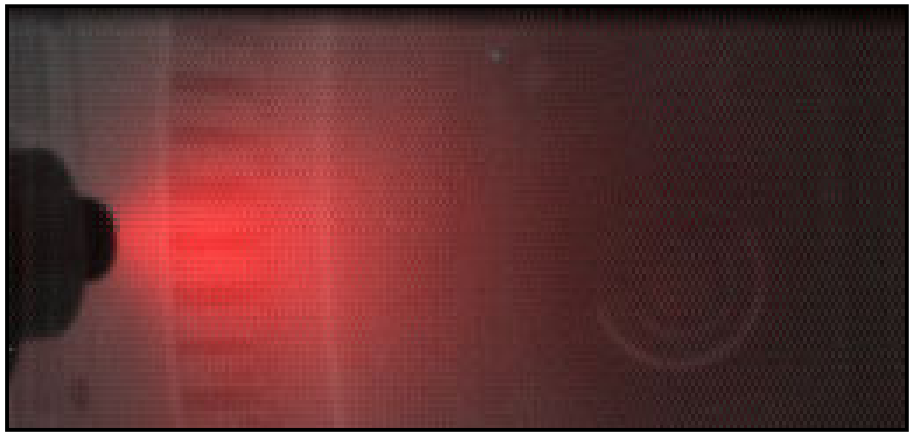
Toroidal gap shorted by migrated lithium

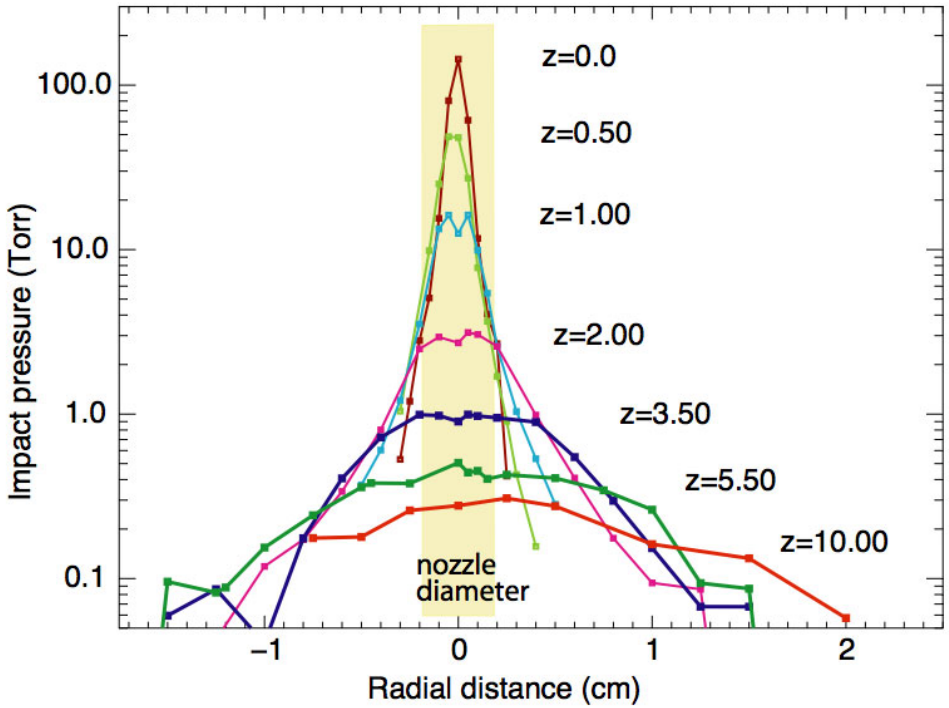


Toroidal current during "swing" in Ohmic heating current

Further studies of supersonic gas injection (SGI) planned for plasma fueling

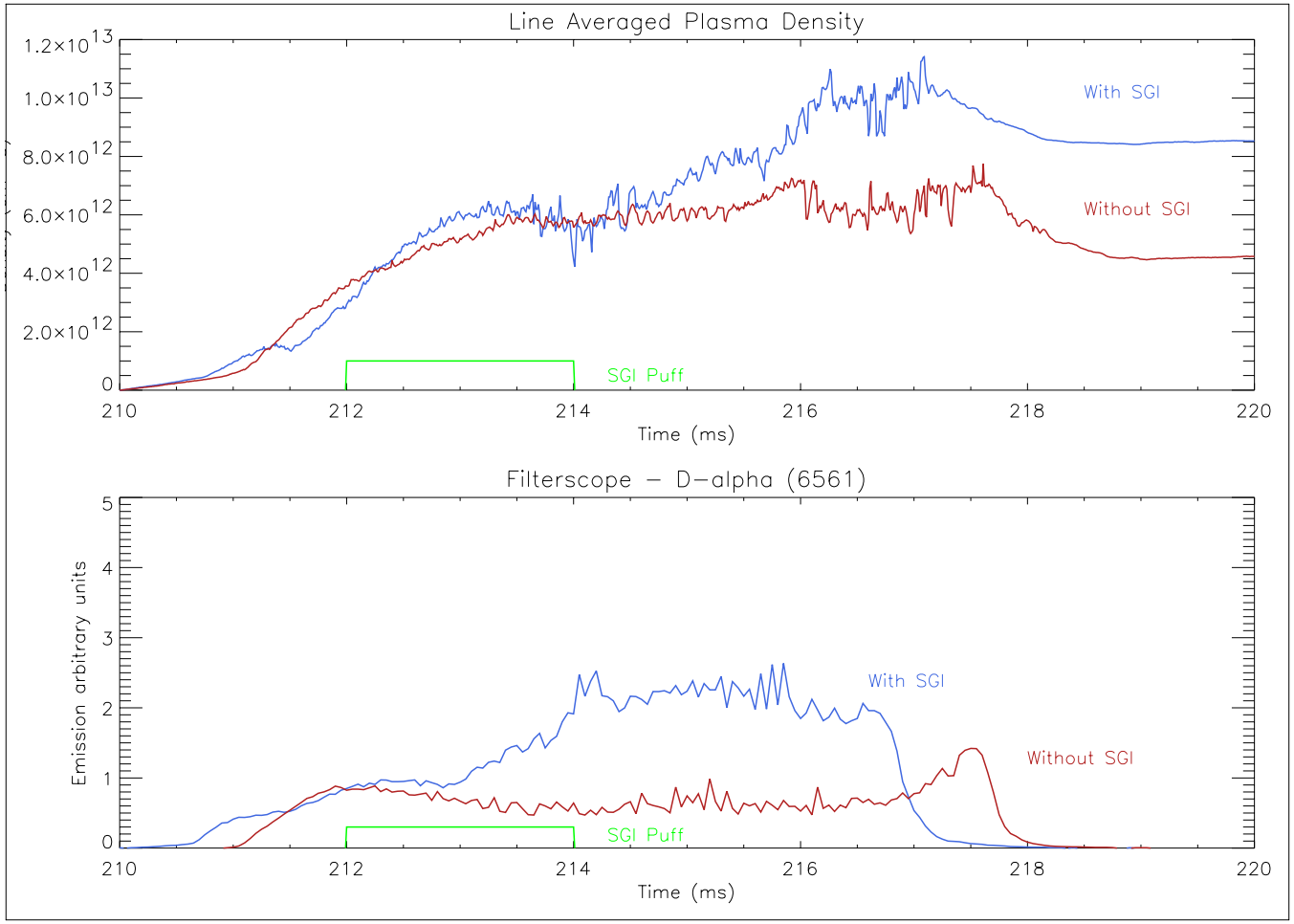
False color image of SGI puff in CDX-U





Jet divergence half-angle: 6°

Preliminary results suggest improvement in fueling efficiency in standard CDX-U discharges



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Summary

- Liquid lithium can be:
  - Low recycling as plasma facing surface
  - Effective at removing impurities
  - Stable in the absence of toroidal current paths during a tokamak discharge
- Tokamak discharges operated with a liquid lithium limiter show evidence of beneficial equilibrium modification
  - Efficient loop voltage utilization observed
- Control of “thermomechanical” lithium flow (“wetting”) over clean surfaces under investigation
- Future plans include:
  - Supersonic gas injection and pellet injection
  - Test of coating system for National Spherical Torus Experiment (NSTX) and new Lithium Tokamak Experiment (LTX)
    - » Lithium will be evaporated onto sample heated carbon tiles