Latest results from the liquid lithium experiments in CDX-U

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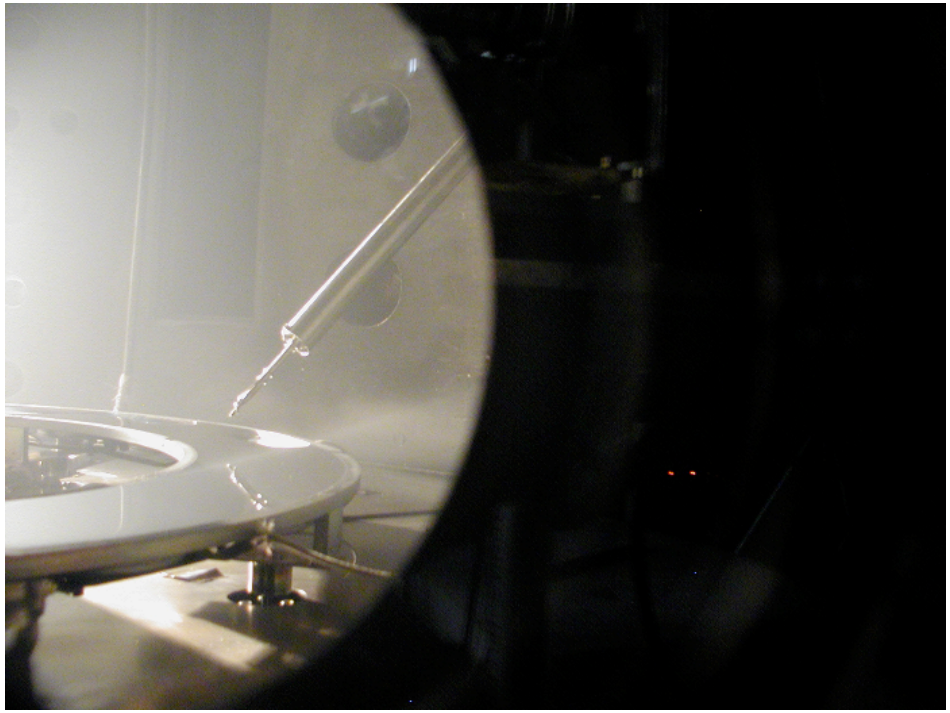
Two fills of the CDX-U lithium tray were performed by UCSD this year

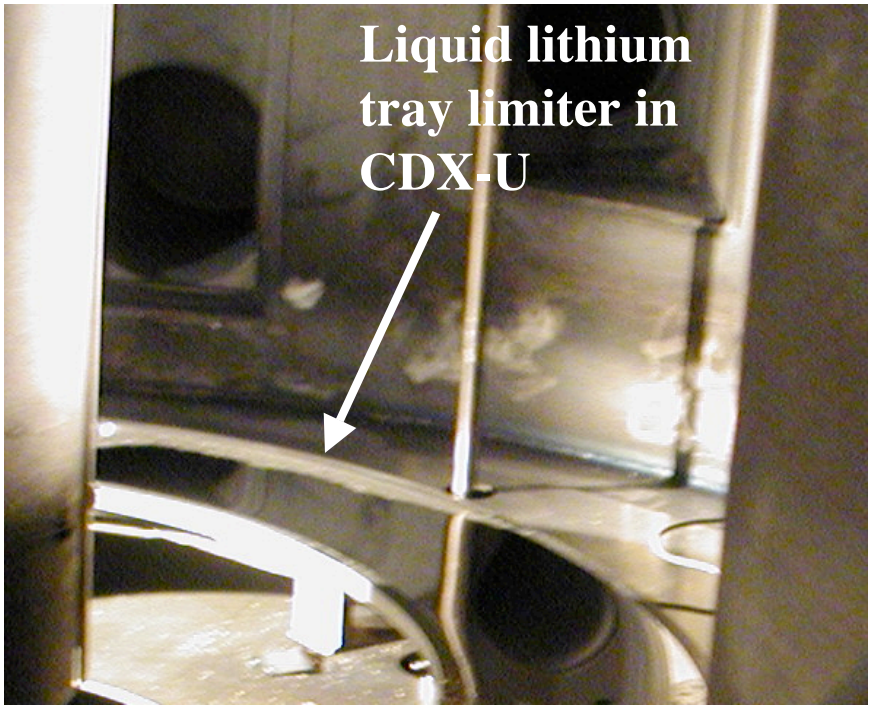
- First fill: early May
  - Achieved full tray coverage.
  - Able to maintain a clean surface for over a month.
  - CDX-U operation required up to an 8□ increase in fueling.
  - Loop voltage decreased to NSTX-like levels
    - » Previously unprecedented in a small tokamak
  - Immediate increase of peak plasma current after fill
  - Indications of low Z_{eff} reassuring
  - NO motion of the bulk lithium whatever observed
- Very successful ~ 1 month plasma run followed
- Then an interferometer window broke
  - Machine vented to air - safely! No fires, etc.

CDX-U began new lithium experiments in May

- 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



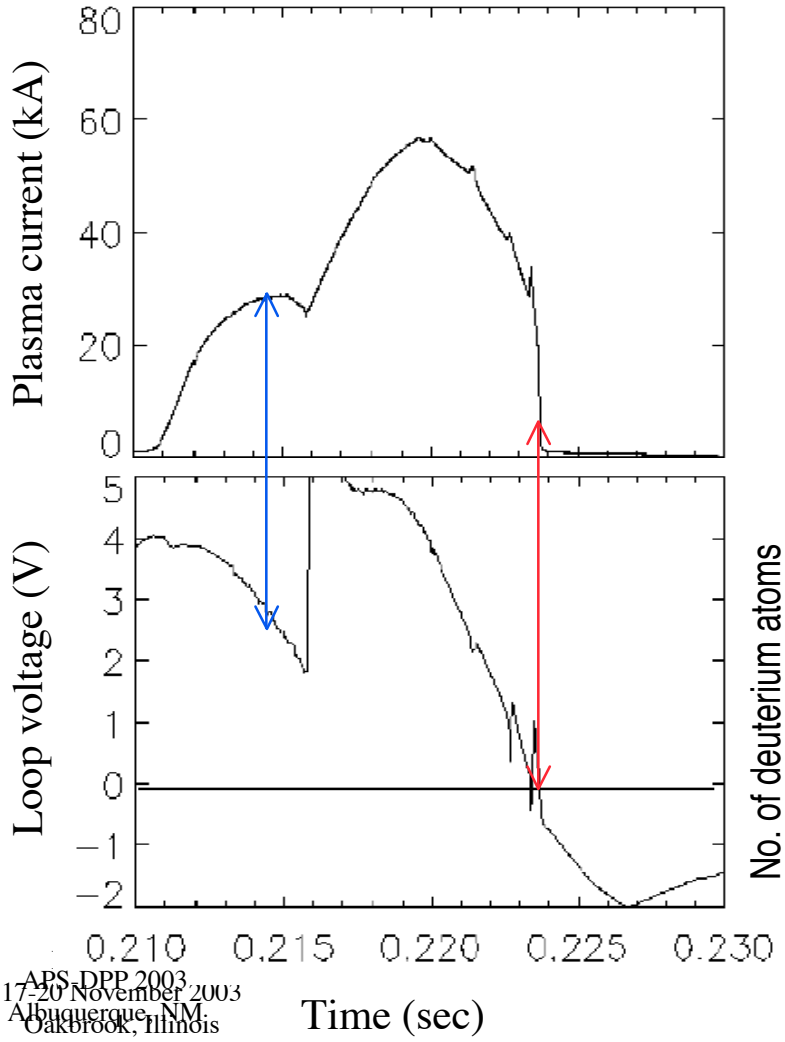
Injector and tray immediately after fill

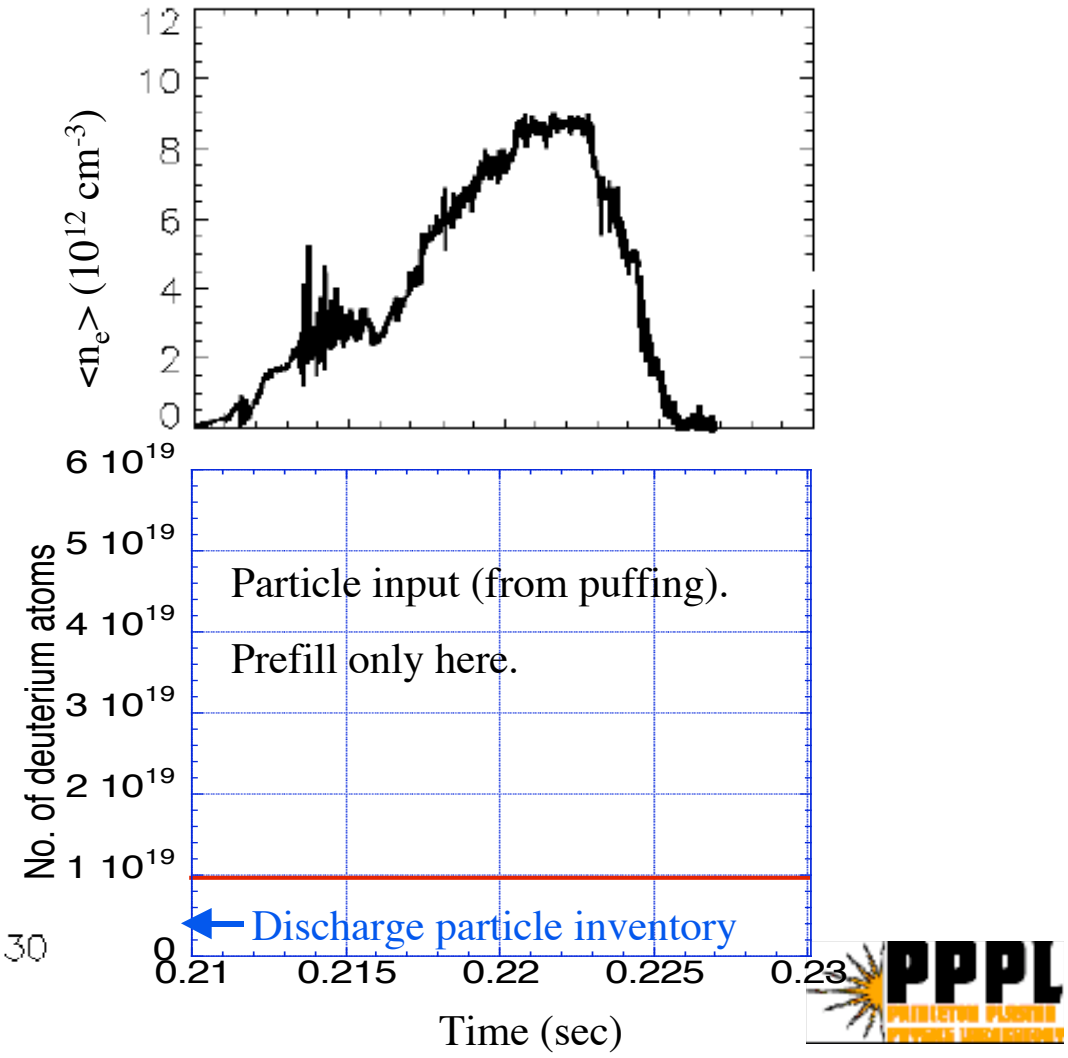


Tray after ~40 discharges.

A pre-lithium discharge

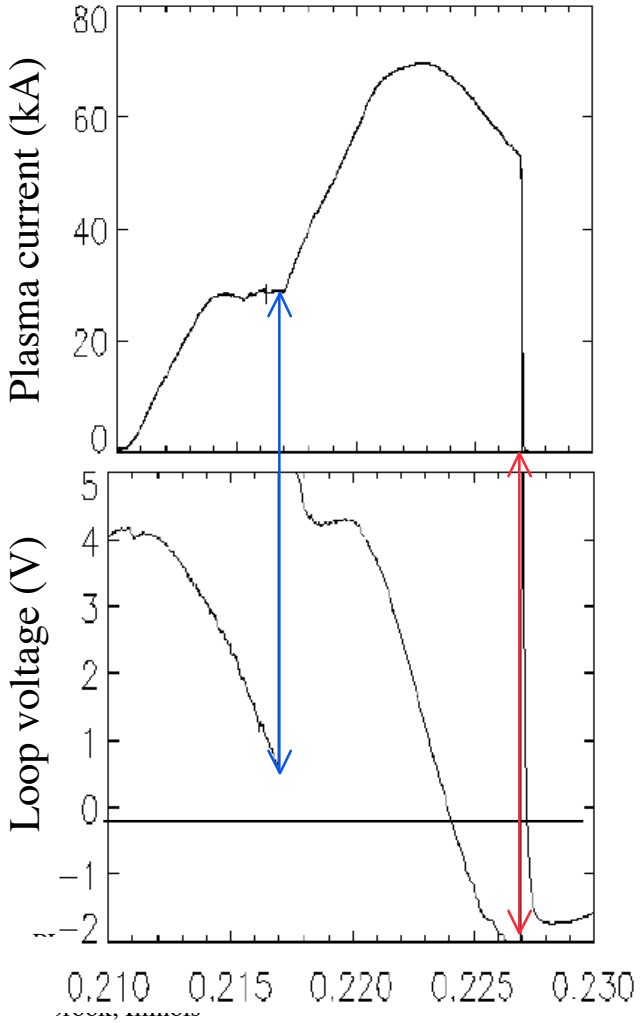
- Plasma current requires 2V or more for sustainment. Terminates when $V_L \approx 0$
- Prefill only fuels the entire discharge.

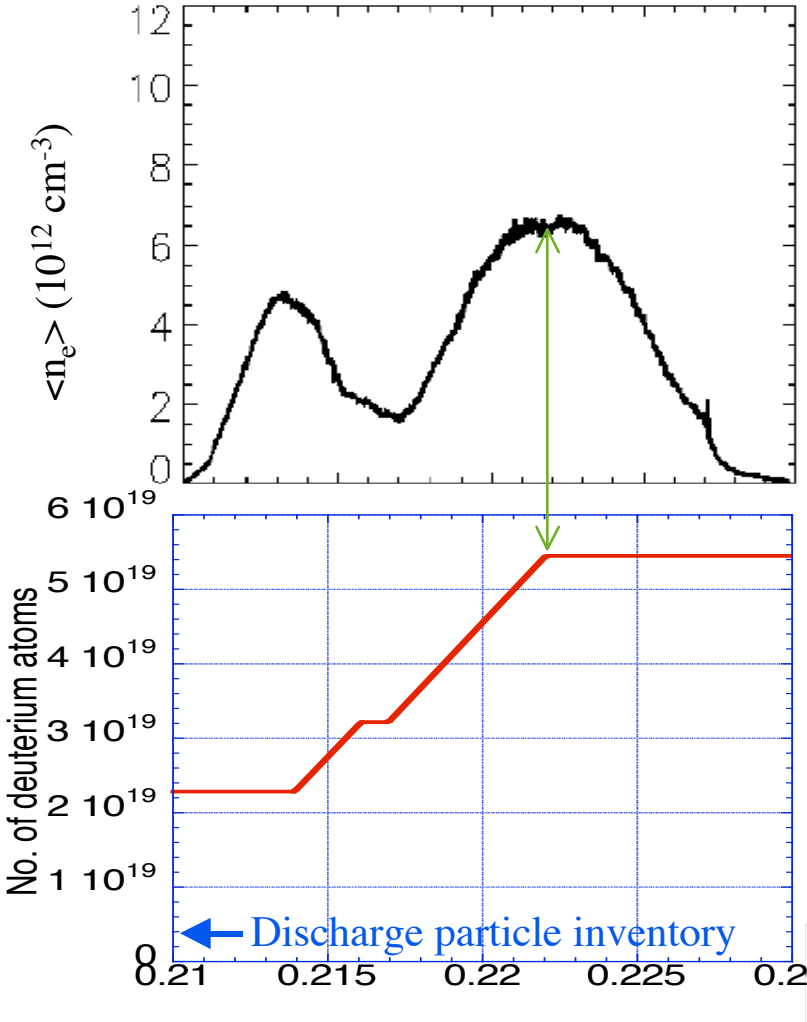




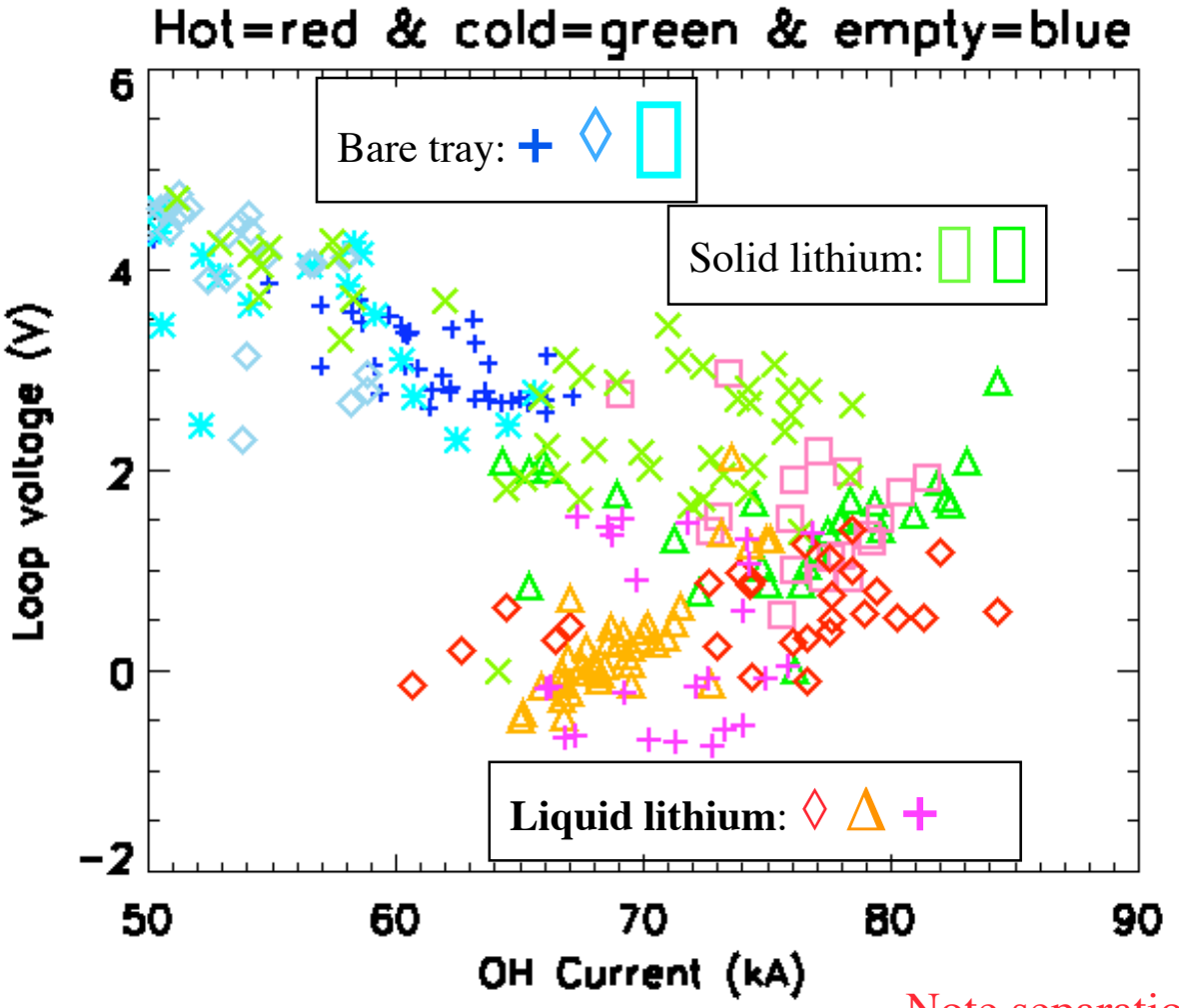
A post lithium discharge

- Plasma current requires < **0.5V** for sustainment. Does not terminate until V_L ≈ **-2V**
- Fueling requirement increases by 5-8 ×. Density begins to pump out within ~1msec of cessation of puffing.





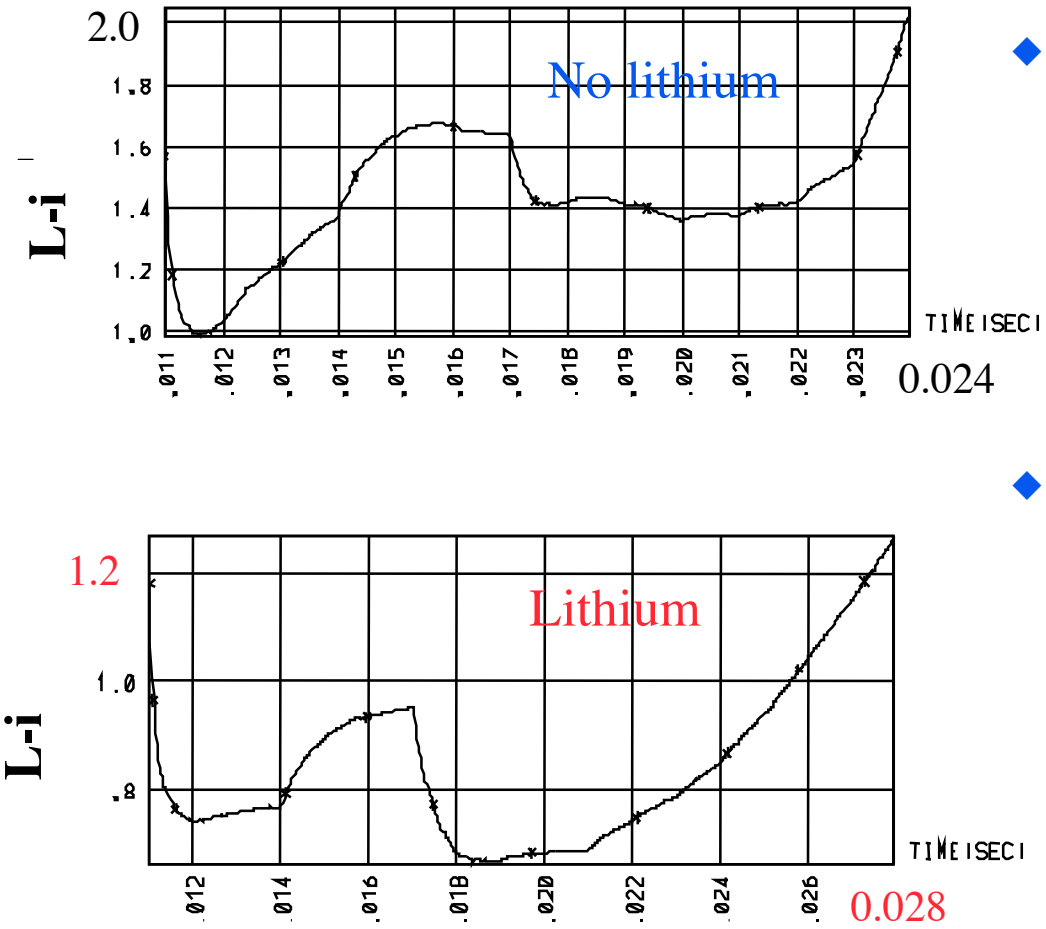
CDX operates at greatly reduced V_L with liquid lithium



- CDX-U utilizes a capacitor bank
  - Fixed V_L waveform
- Clear drop in V_L from no lithium > cold lithium > hot lithium > hot, clean lithium
- Discharge duration also increases by 17%

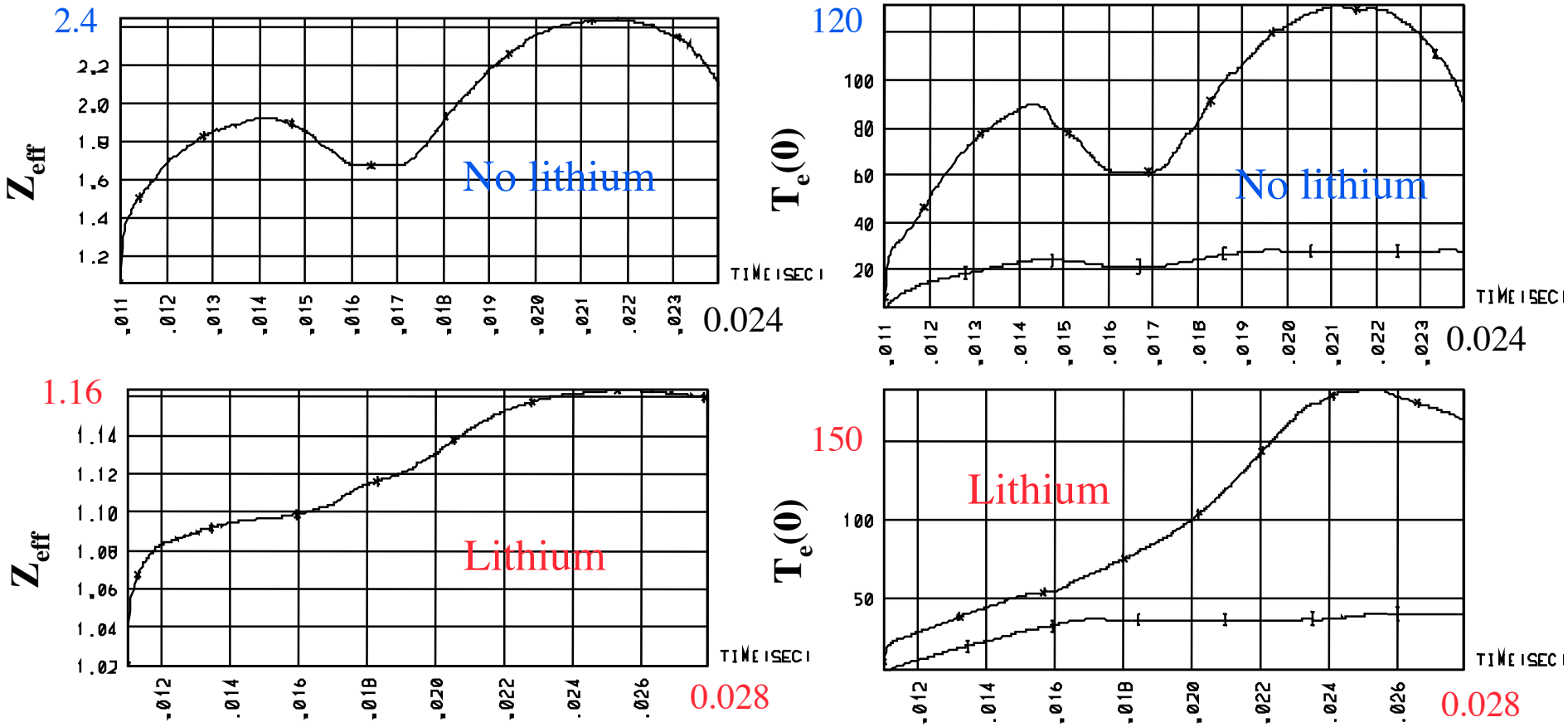
Note separation of lithium, non-lithium data

TSC simulations give insight into discharge behavior



- 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

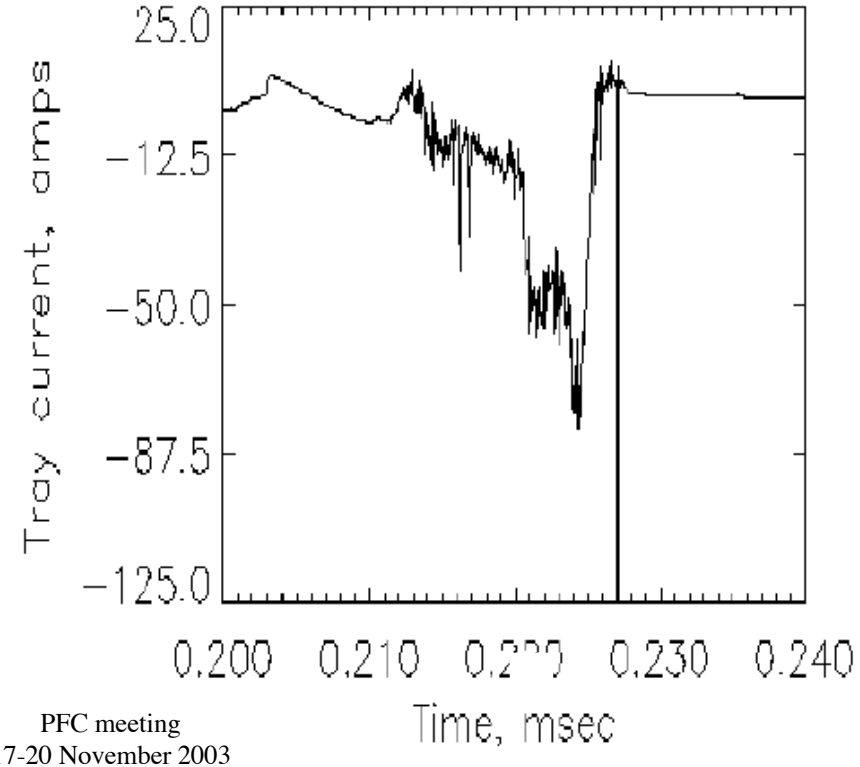
TSC simulations indicated very low Z_{eff} with lithium

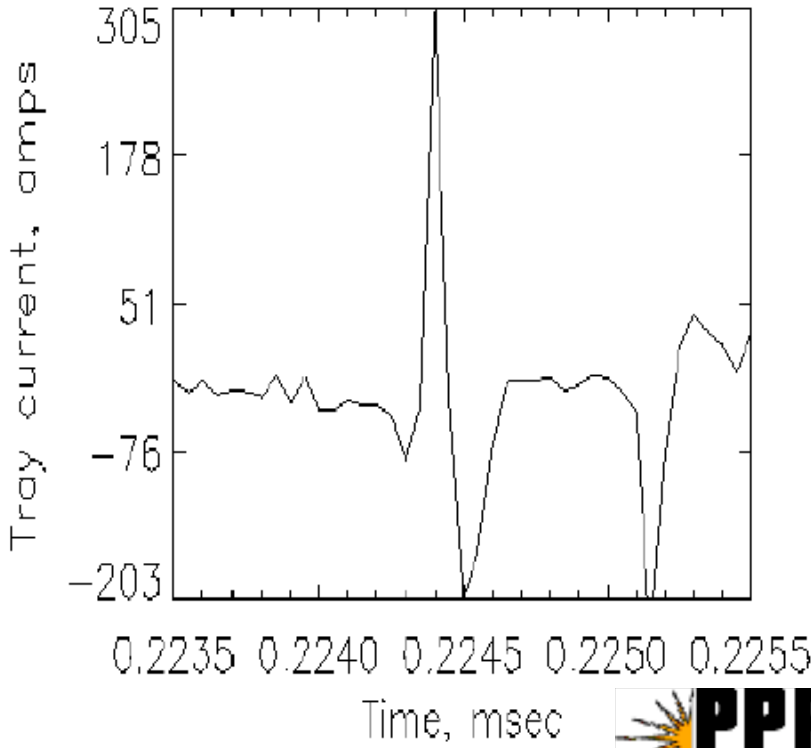


- Soft x-ray emission supported peak temperature (with lithium) of not more than ~150 eV
  - Used to constrain TSC modeling
- Observed plasma resistivity (with lithium) requires very low Z_{eff}

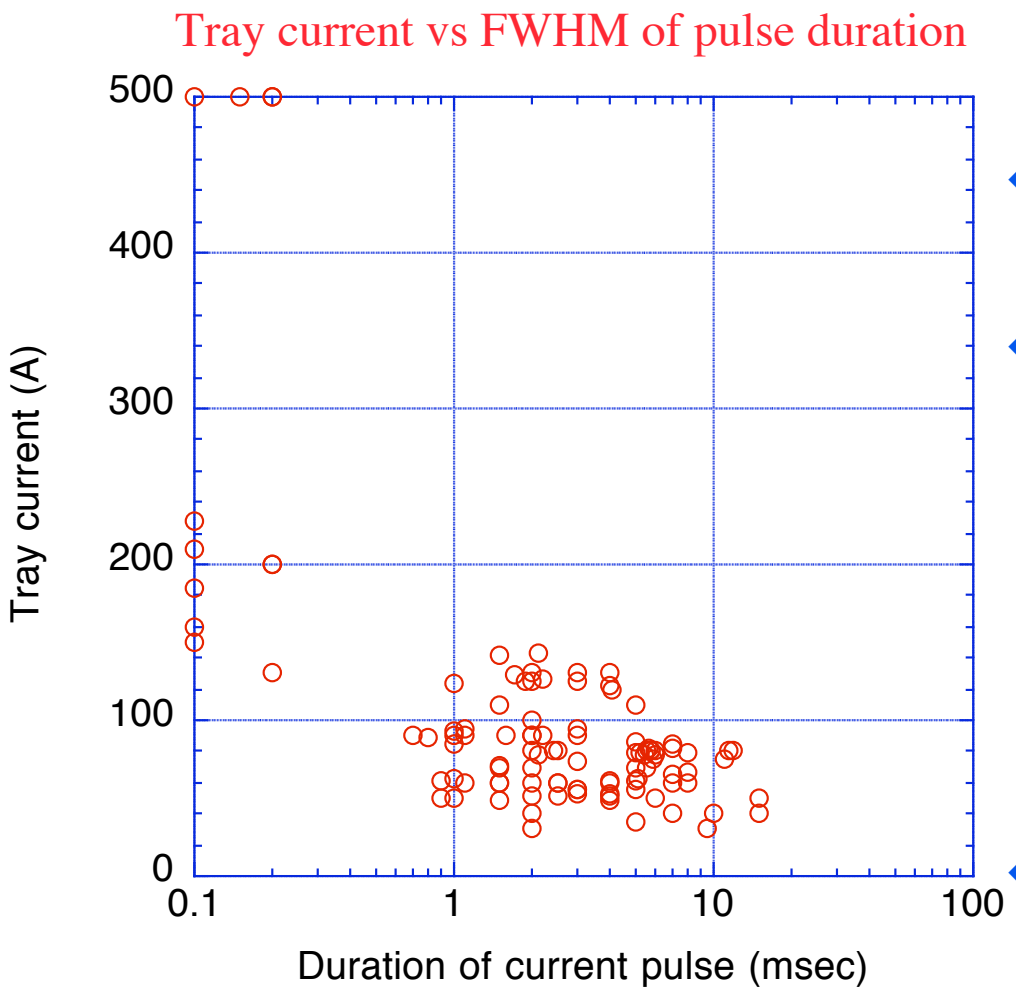
Liquid lithium PFC is mechanically stable in CDX-U

- No motion of the liquid has been observed with a fast framing camera
- No unipolar arcing
- No spatter, droplets, etc on the vessel floor
- Current to the liquid during a discharge is routinely ~100A
  - Occasionally 500A or greater during plasma termination





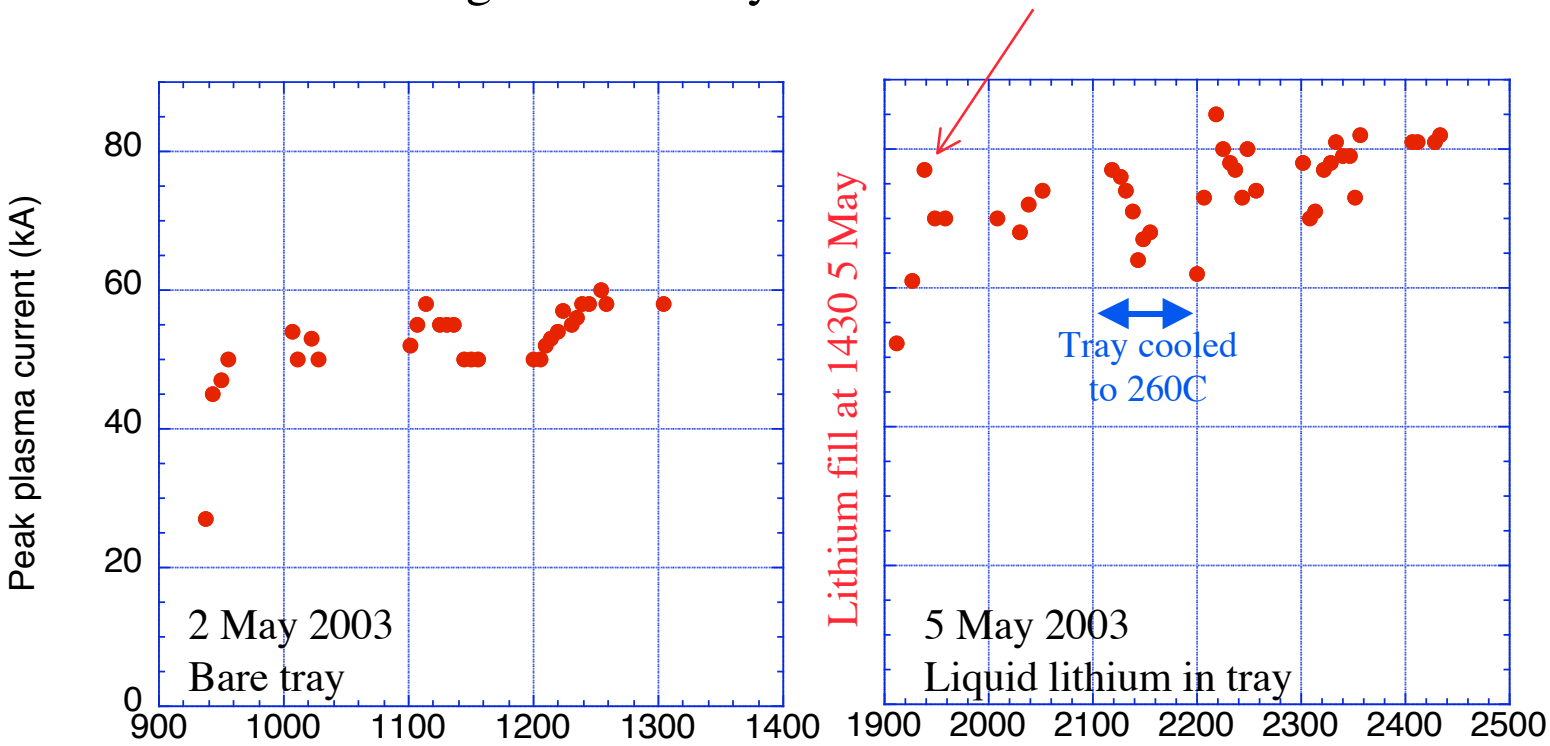
Tray current observations



- ~75% of liquid lithium shots included in database
  - >100 discharges with tray current >20A
- Tray geometry ensures that full current flows through cross section of SS tray/lithium fill
- At 300C, >70% of the tray current flowed in the lithium
  - Lithium cross sectional area ~ 4 cm^2
  - Current density commonly 20-30 A/cm^2 for several msec
  - Short pulses up to $100A/cm^2$
  - Tray design ensures current flows to ground in toroidal direction
- Lithium remained stable

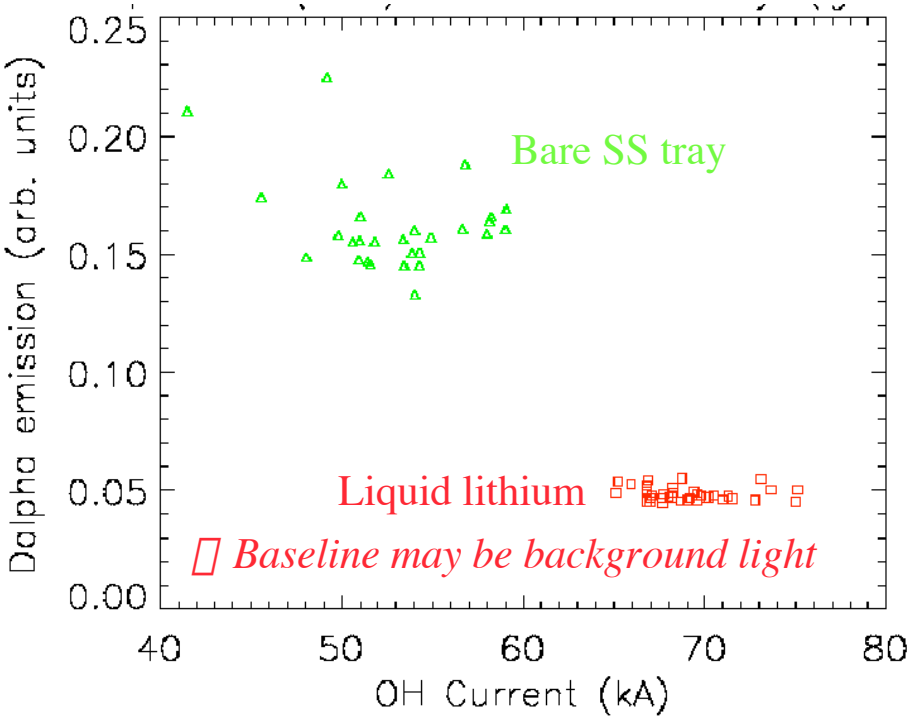
Plasmas limited by liquid lithium showed an immediate increase in peak current

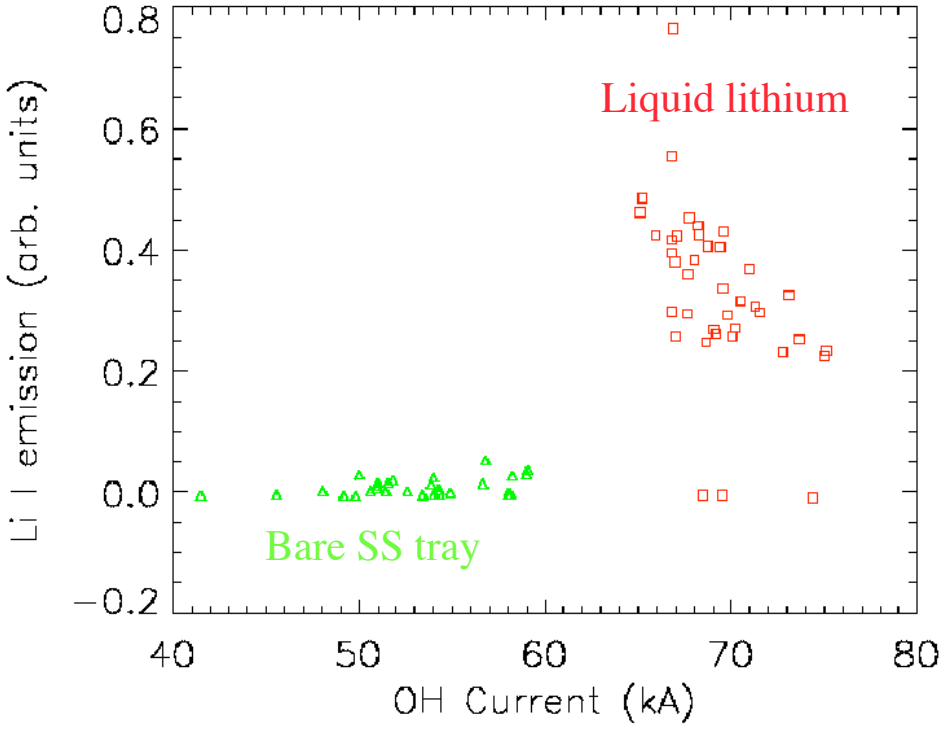
- No conditioning of the lithium surface was needed.
- First 2 shots on lithium were gas starved.
  - Total fueling increased by 4x for 3rd shot



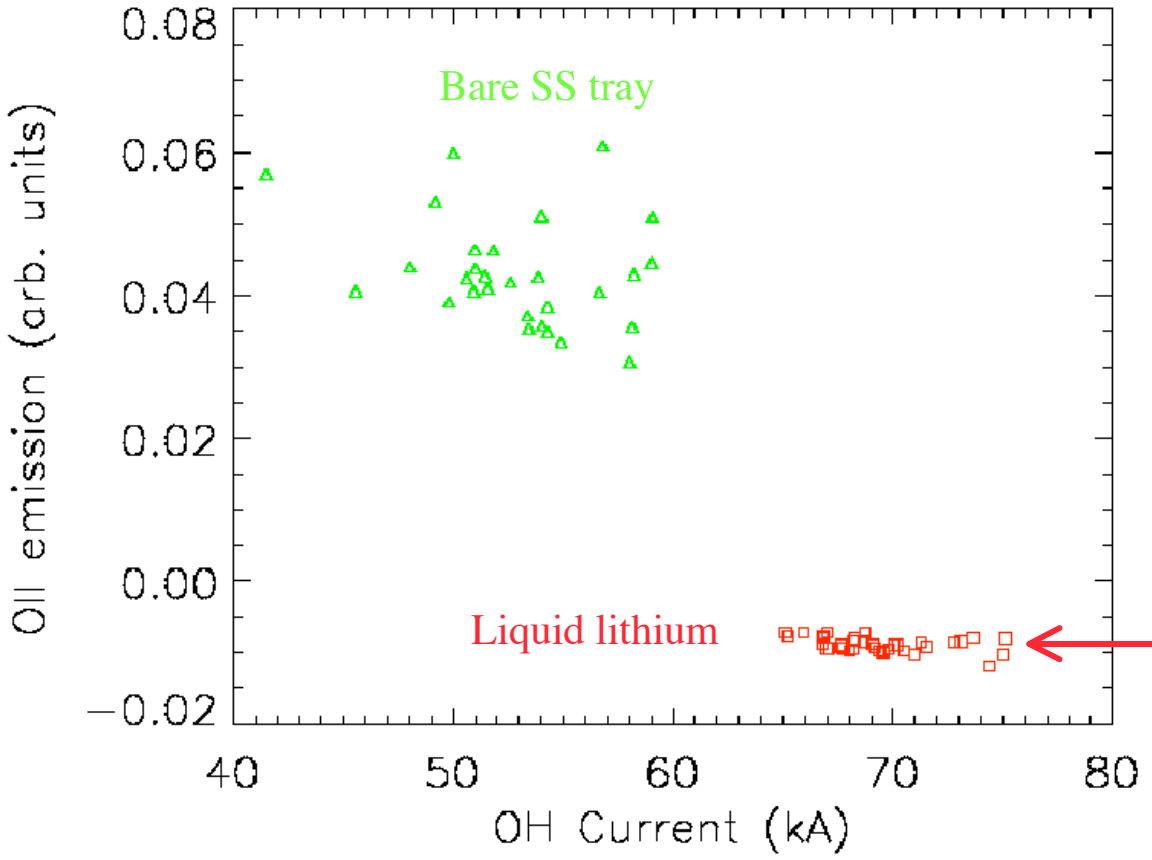
Global recycling reduced with liquid Li limiter

- Comparisons of emissions from the centerstack filterscope.
  - Indicative of global $D_{\square}$
- Strong lithium emissions at centerstack probably due to coatings
  - Centerstack lithium is solid





Oxygen is strongly reduced



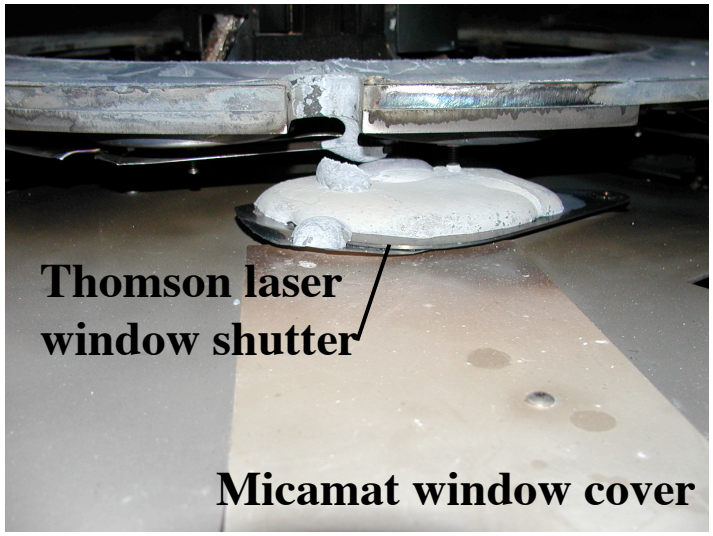
Digitizer drift. Oxygen emission at the centerstack is now zero

Second FY03 tray fill

- In early June the upper interferometer window on the CDX-U vacuum vessel cracked during a tray heating and discharge cleaning run.
  - Emergency pumping system maintained vessel pressure below ~10 Torr despite cracked window.
  - Tray cooled rapidly to below melting point.
  - No fire; only surface of lithium was visibly reacted (gray).
- CDX vented, window replaced and seal modified.
  - Upper vessel flange determined to be warped.
- Tray refilled in September. Multiple problems.
  - Heaters shorted; leads opened up.
  - Lithium wicked into gap between tray halves; flowed onto lower Thomson scattering window (lots of it).
  - Still diagnosing problems.
  - Also note that surface of lithium was coated *immediately* following fill.

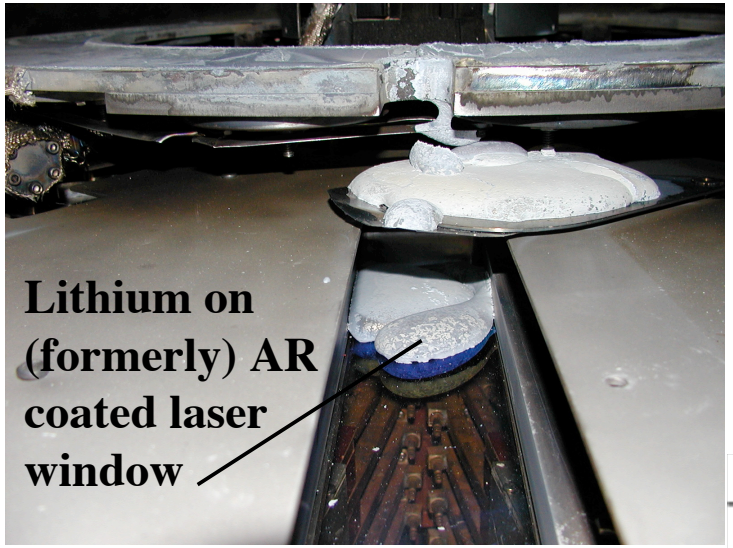
Second fill aftermath. CDX was vented on 11/12.

Tray at Thomson laser window



(nearly) Full view of tray

As above, with window protection removed



Plans for FY04

- Analysis of the data from May still underway
- Results of TSC simulations indicated that one of the primary predictions for lithium walled tokamaks may have been verified
  - Strong drop in L_i indicates significant broadening of the current channel
  - Implies broadening of the T_e profile.
- These and other results provide impetus for one more tray fill.
  - Scheduled for early January.
- Improved diagnostics will be available.
- Following this fill, CDX will be modified for the module A tests.
  - March-April time frame
- CDX will be completely disassembled in late FY04-early FY05.
  - Reassembled as LTX in late FY05/early FY06

Summary

- Liquid lithium can be:
  - Mechanically stable during a tokamak discharge
  - Low recycling
  - Effective at removing impurities
- Puffing + low recycling walls provides better discharge performance than prefill + recycling walls
  - Not entirely expected
- Tokamak discharges operated with a liquid lithium limiter show evidence of equilibrium modification
- Tray experiments will resume
- Followed by module A tests for NSTX
- LTX will replace CDX in FY05.