CDX-U

LTX

Progress and plans for the CDX-U liquid lithium experiments

Presented by Dick Majeski

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PFC meeting
3-5 May 2004
University of Illinois - Urbana

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Recap of 03 - 04

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- First successful lithium fill with UCSD: early May 03
  - Eventually produced full tray coverage; clean lithium surface via hot (300C) argon glow discharge cleaning.
  - CDX-U operation required up to an 8× increase in fueling.
  - Loop voltage decreased to NSTX-like levels
  - NO motion of the bulk lithium whatever observed
  - Fracture in interferometer window terminated run
- Second fill: September 03
  - Heaters shorted; leads opened up.
  - Lithium wicked into gap between tray halves; flowed onto lower Thomson scattering window (lots of it).
  - Limited data obtained.
- Third fill: April 28, 2004
  - 50% initial coverage
    - » Lithium coverage increased to >95%, surface cleaned up under hot discharge cleaning.
  - Initial results indicate that plasma performance is comparable to last May.

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First successful fill in May 03

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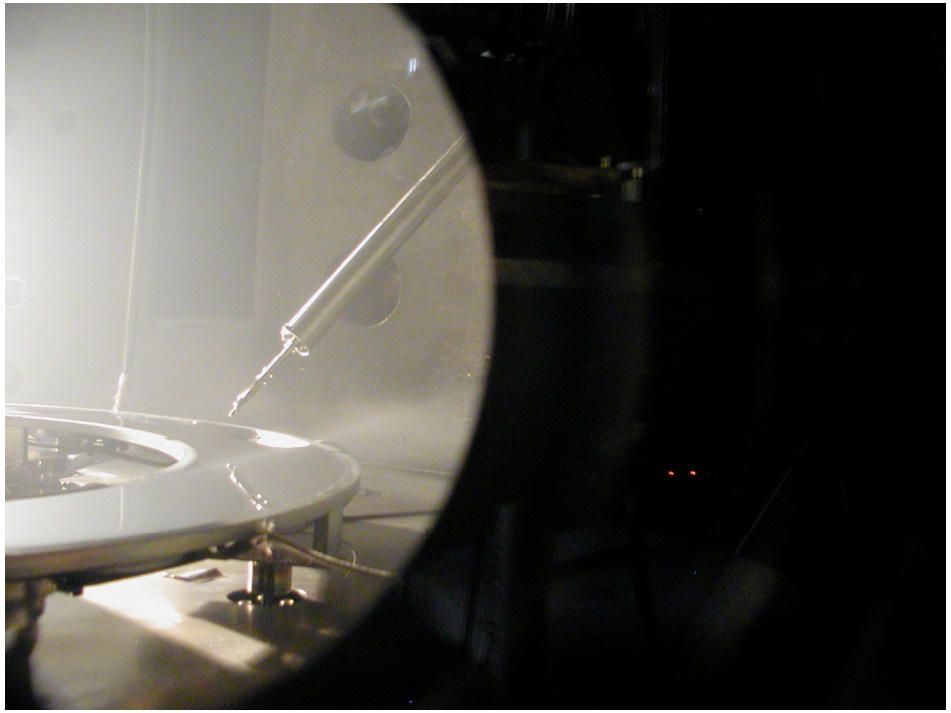
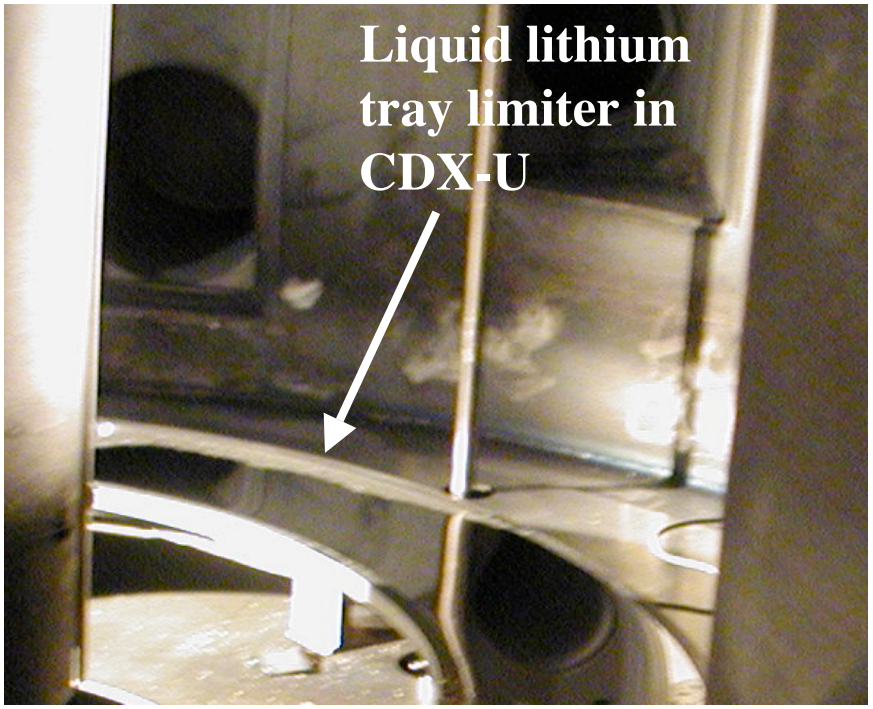
- New filling technique (UCSD)
  - Load liquid lithium onto 500°C tray
  - Tray coverage ~80%
- Only thin coatings appear between runs
  - Removed by argon glow, heating
- **NO** mobilization of the lithium



Injector and tray immediately after fill



Tray after ~40 discharges.

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A pre-lithium discharge

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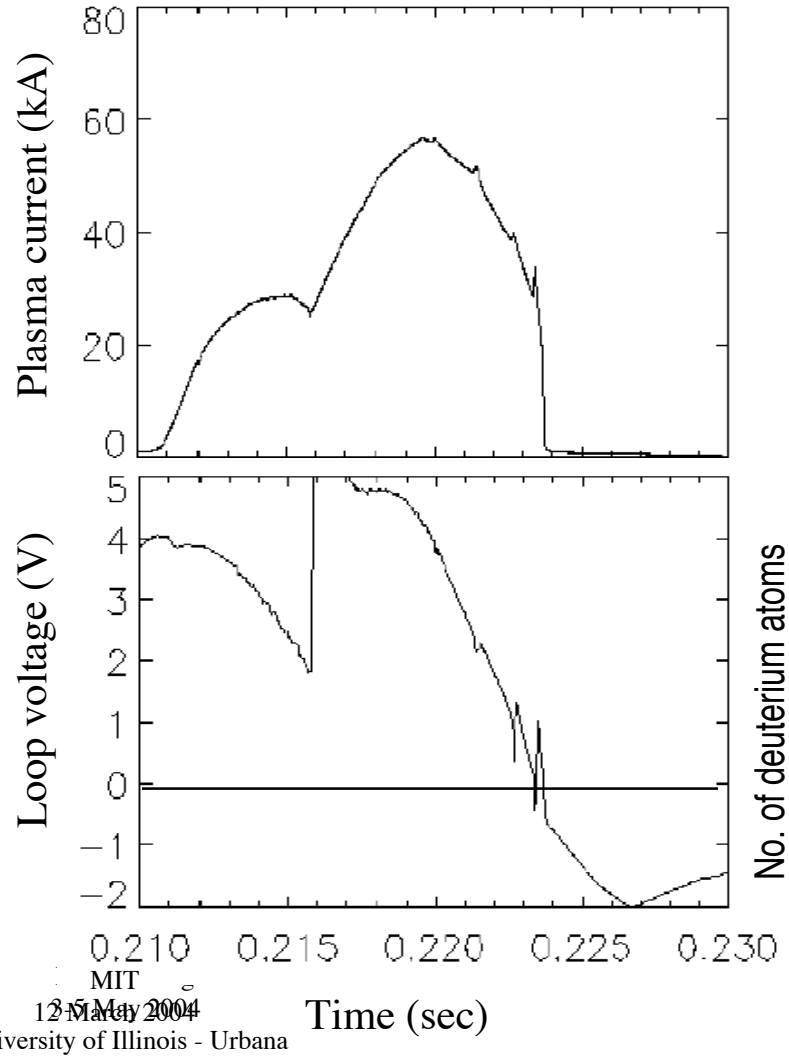
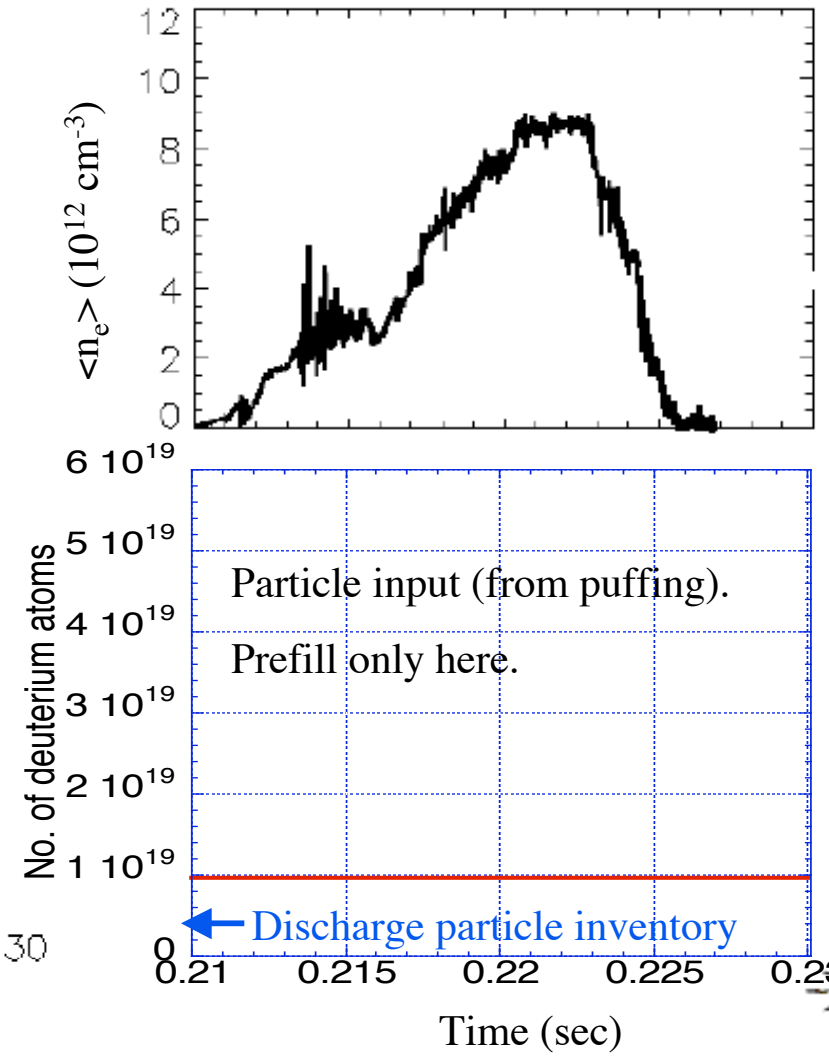
- Plasma current requires 2V or more for sustainment. Terminates when $V_L \Rightarrow 0$
- Prefill only fuels the entire discharge.





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A post lithium discharge

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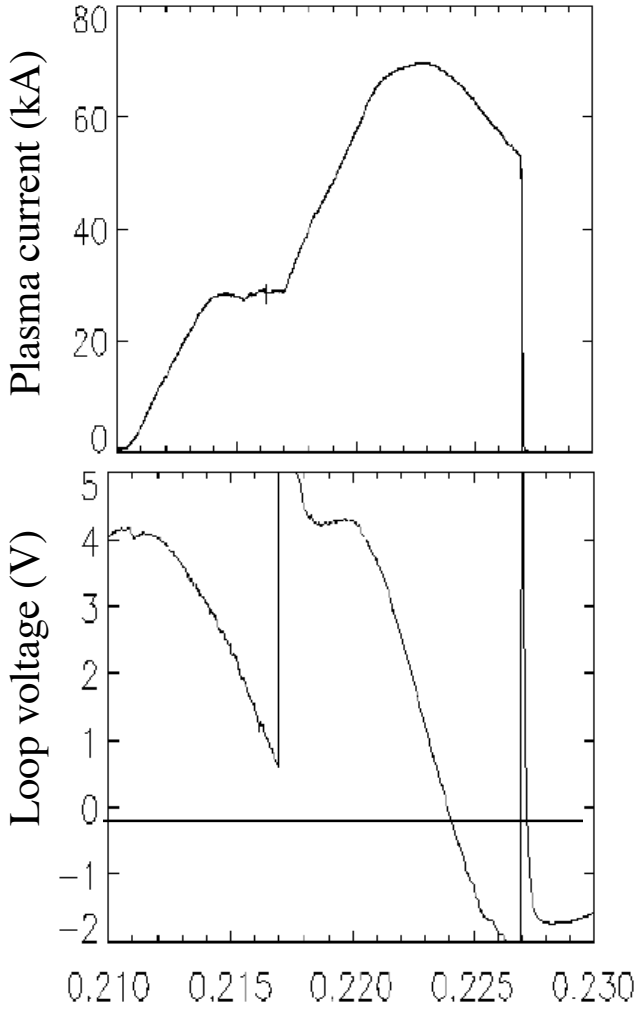
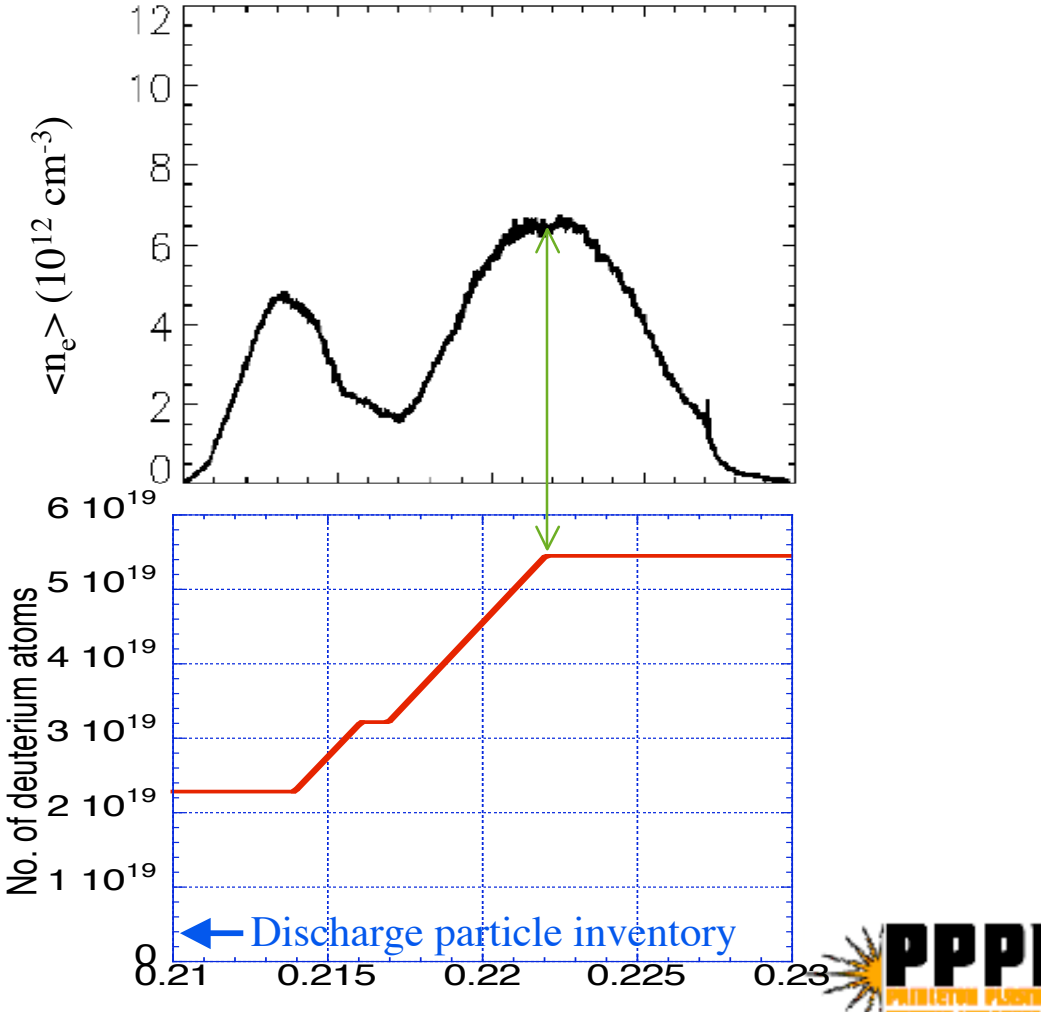
- Plasma current requires < **0.5V** for sustainment. Does not terminate until $V_L \Rightarrow$ **-2V**
- Fueling requirement increases by 5-8 ×. Density begins to pump out within ~1msec of cessation of puffing.





First fill summary - Reduced V_L with liquid lithium

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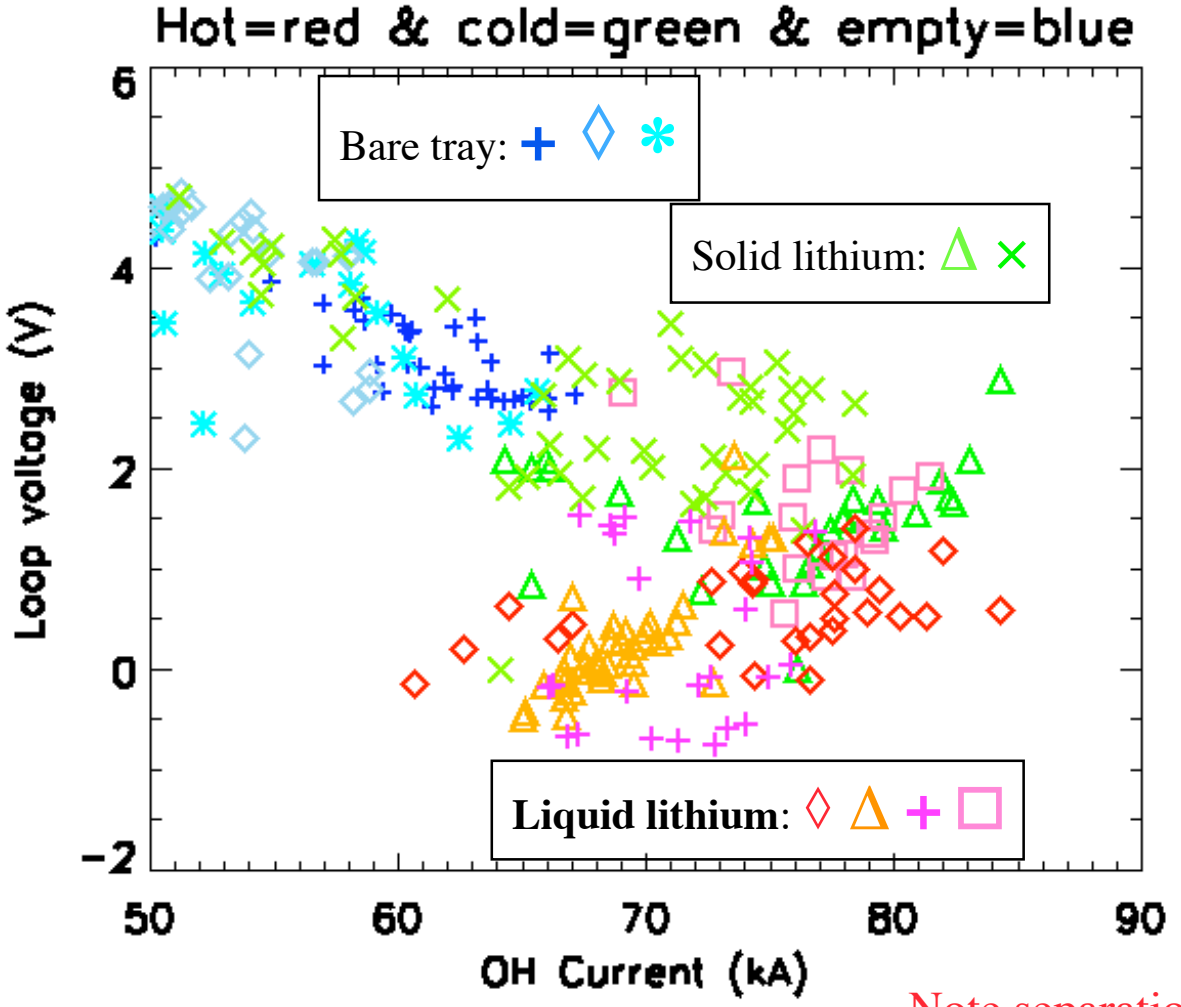

- CDX-U utilizes a capacitor bank
  - Fixed V_L waveform
- Clear drop in V_L from no lithium > cold lithium > hot lithium > hot, clean lithium
- Discharge duration also increases by 17%

Note separation of lithium, non-lithium data

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First fill summary - TSC simulations indicate broadened current channel

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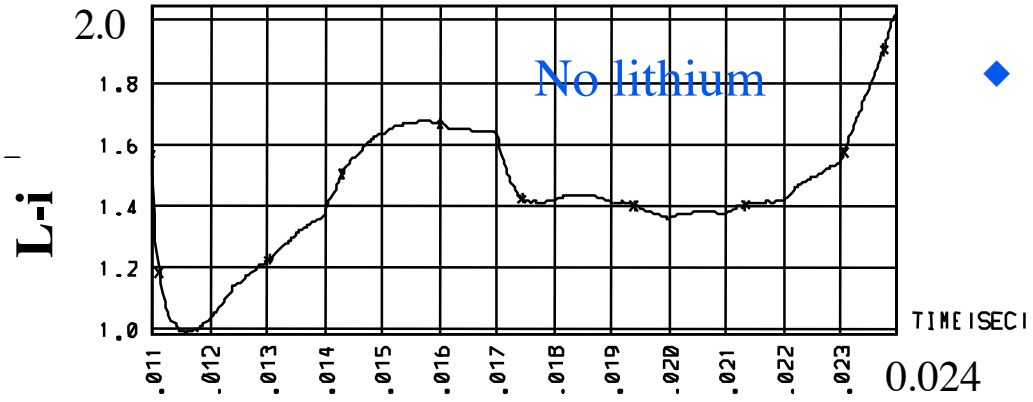

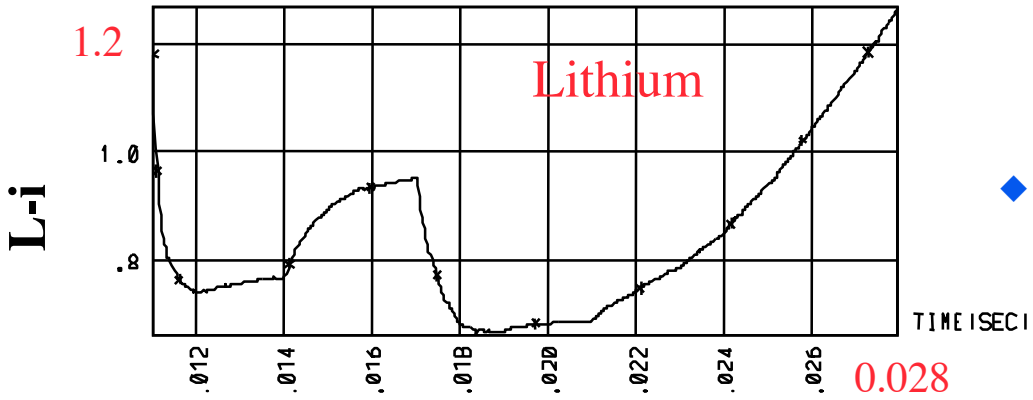

- Characteristics of liquid lithium limited discharges:
  - Low loop voltage
  - Robust nature of discharges
    - » Endured negative loop voltage for several msec
- TSC modeling indicated large difference in plasma internal inductances
  - L_i for lithium discharges ~2× lower
- This result is the primary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

S. Jardin

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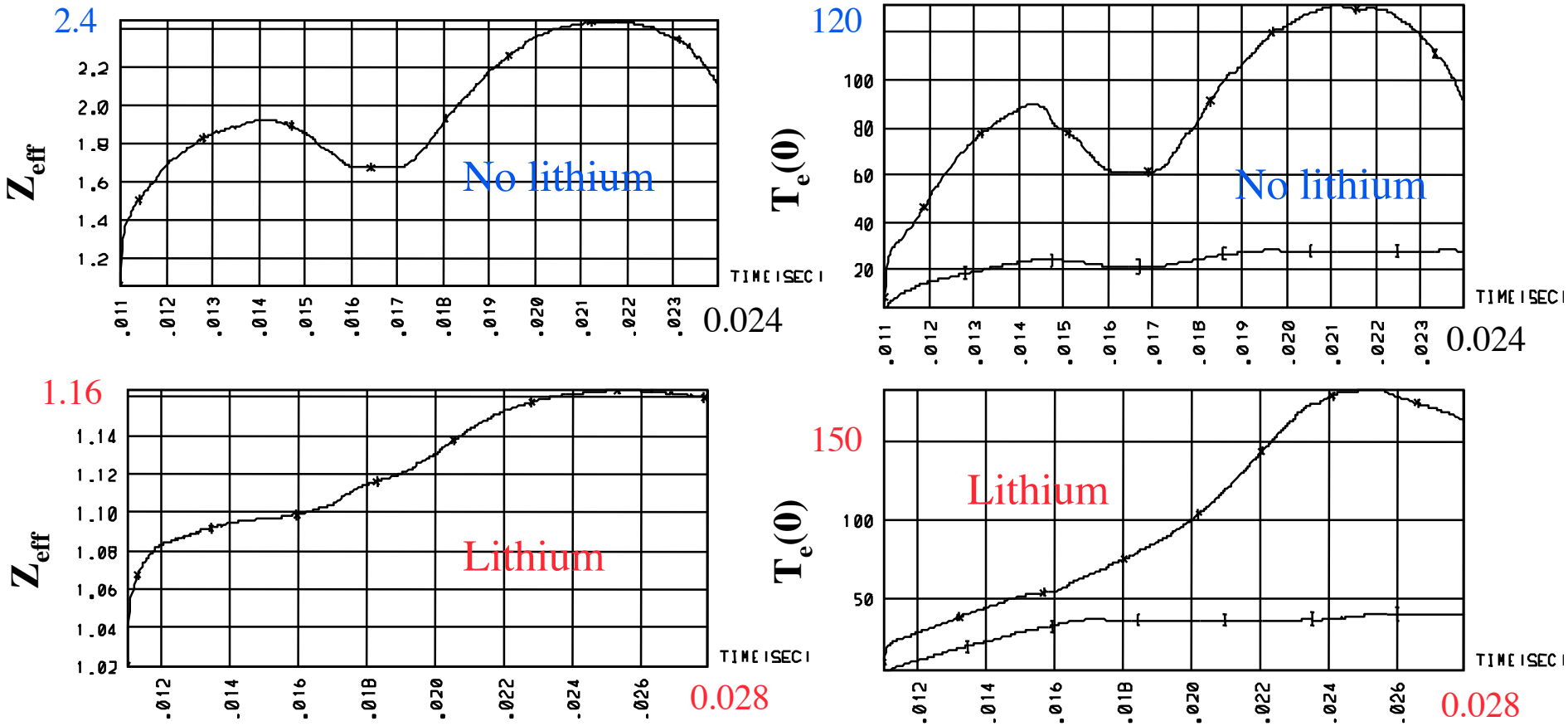
First fill summary - TSC simulations indicated very low Z_{eff} with lithium CDX-U



- 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}

First fill summary - Lithium was completely (mechanically) stable

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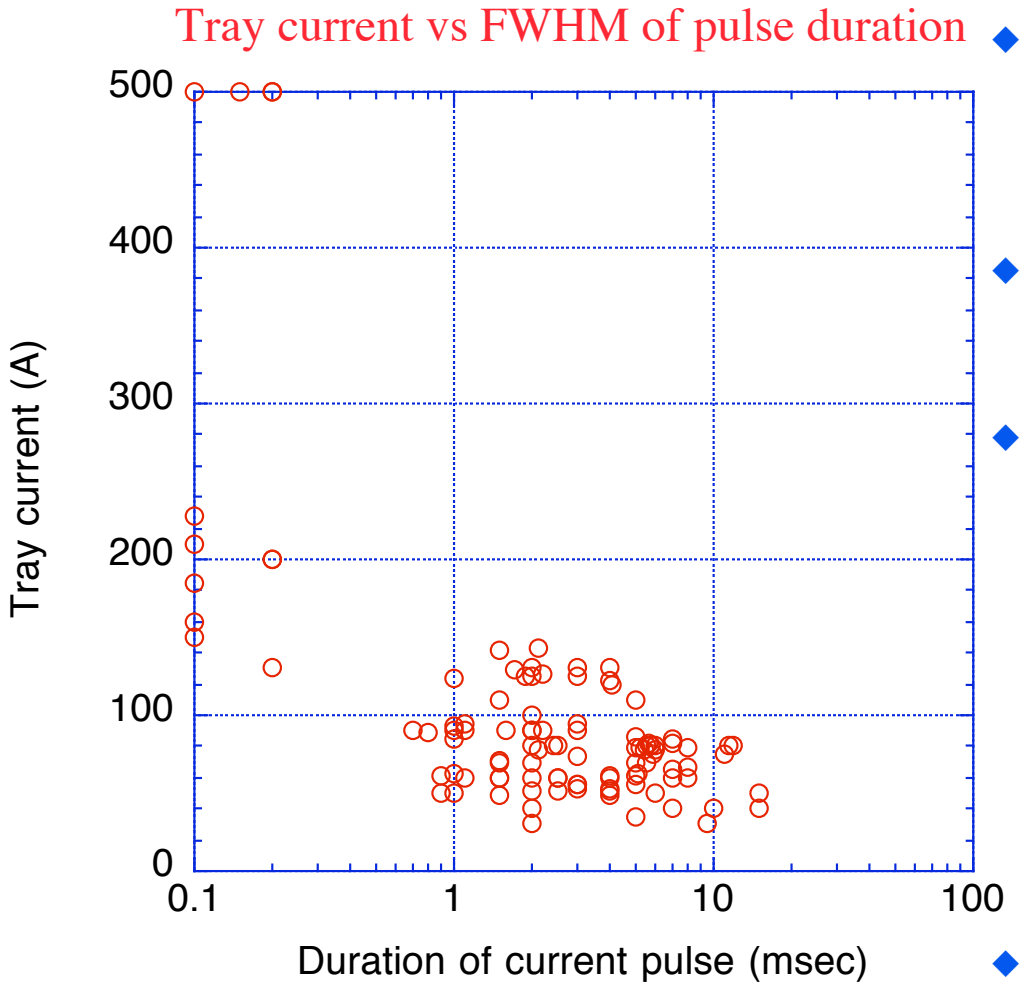

- ~75% of liquid lithium shots included in database
  - >100 discharges with tray current >20A
- Tray geometry ensures that full current flows through cross section of SS tray/lithium fill
- At 300C, >70% of the tray current flowed in the lithium
  - Lithium cross sectional area ~ 4 cm^2
  - Current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

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

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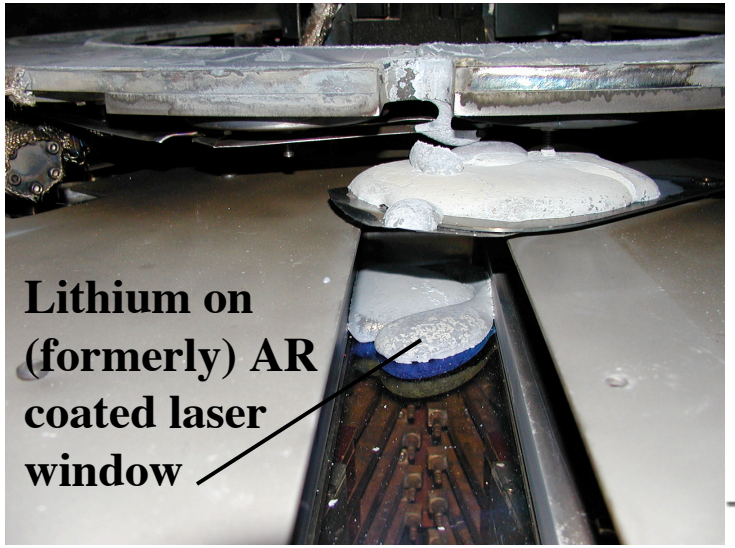
Tray at Thomson laser window

(nearly) Full view of tray

As above, with window protection removed



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Tray was refilled *last week* (preliminary results)

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- UCSD performed a third liquid lithium fill of the tray
- Tray temperature was limited to <500C in order to avoid spillage
  - Reduced quantity of lithium
- Initial fill fraction was only ~50%
  - Argon AC glow + tray heat to 300C promoted additional wetting
  - Coverage as of last Friday was >95%
- Lithium surface cleaned up under the glow
- Problems with window coatings persist
  - Primary difficulty: coating of the interferometer window.
    - » Several solutions available
- New diagnostics:
  - Magnetic reconstruction
  - Ion temperature

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Fill presently covers >95% of tray

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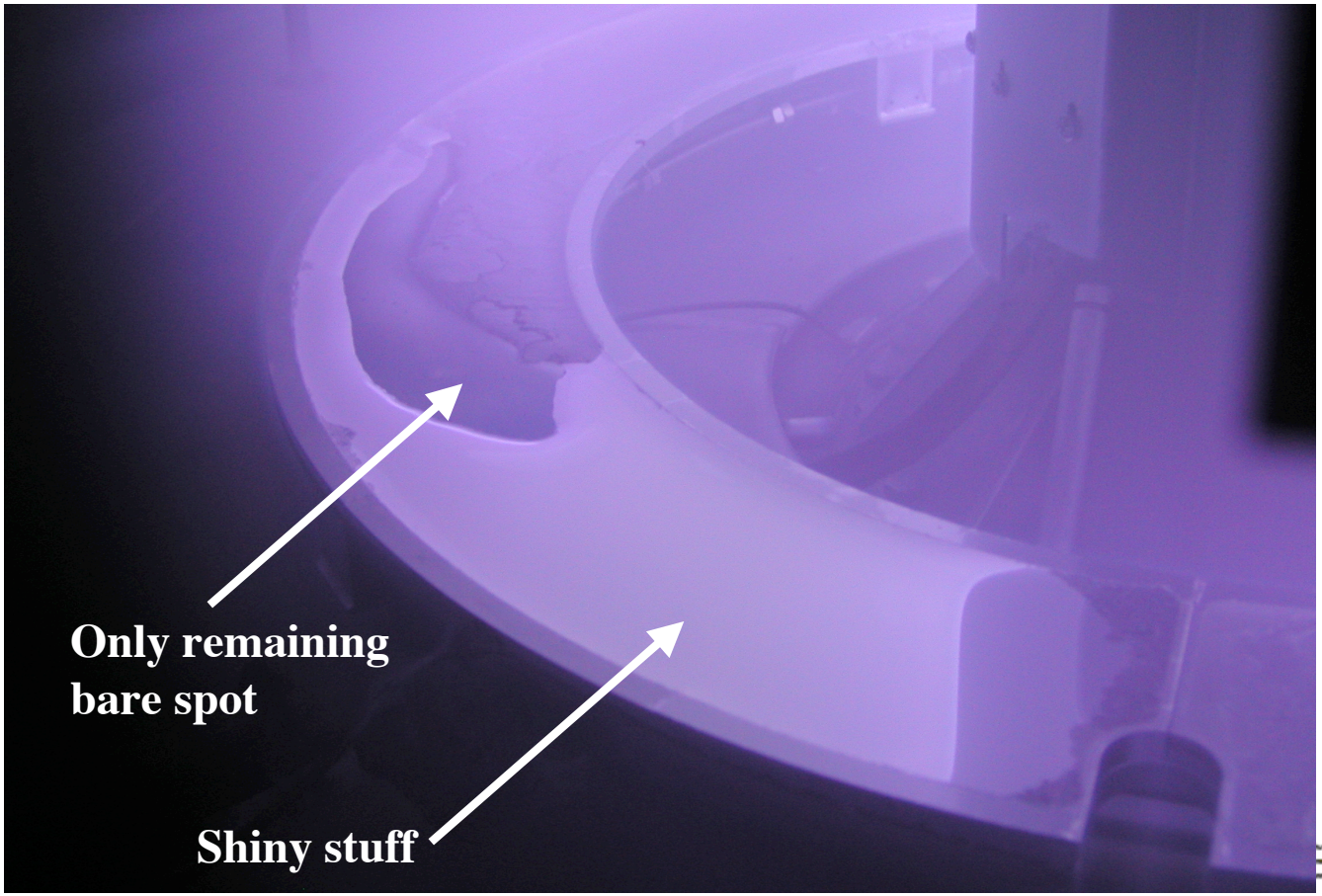
- Tray at 300C (left half only) during argon glow.
  - Shows border of lithium on north tray
  - South tray completely filled
  - Both tray surfaces dominated by specular reflection when lithium is molten



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First Results for the April 04 fill: Lithium shots exhibit far more efficient loop voltage utilization

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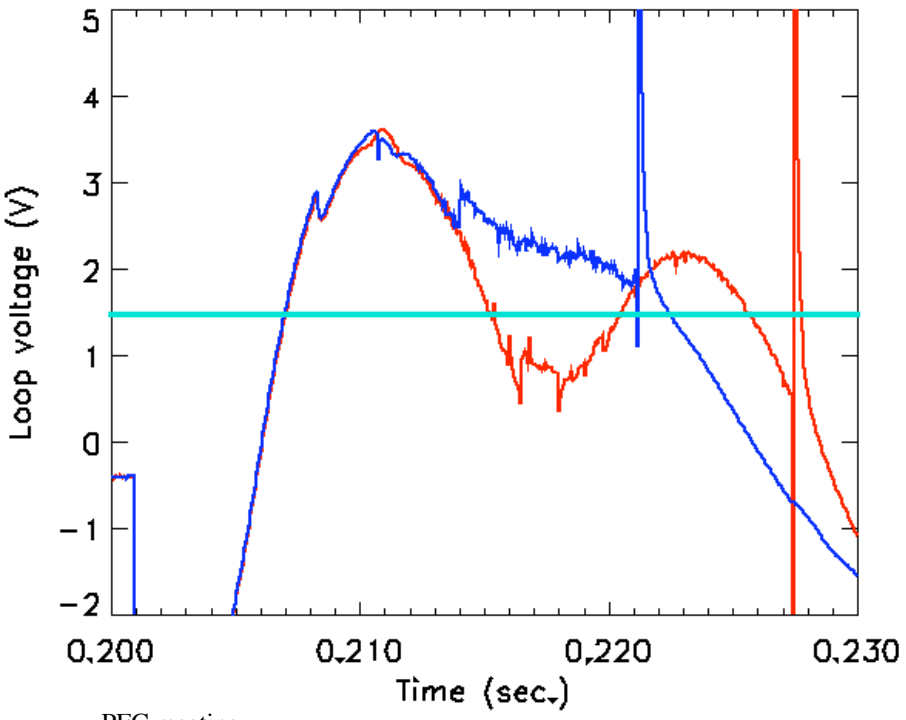
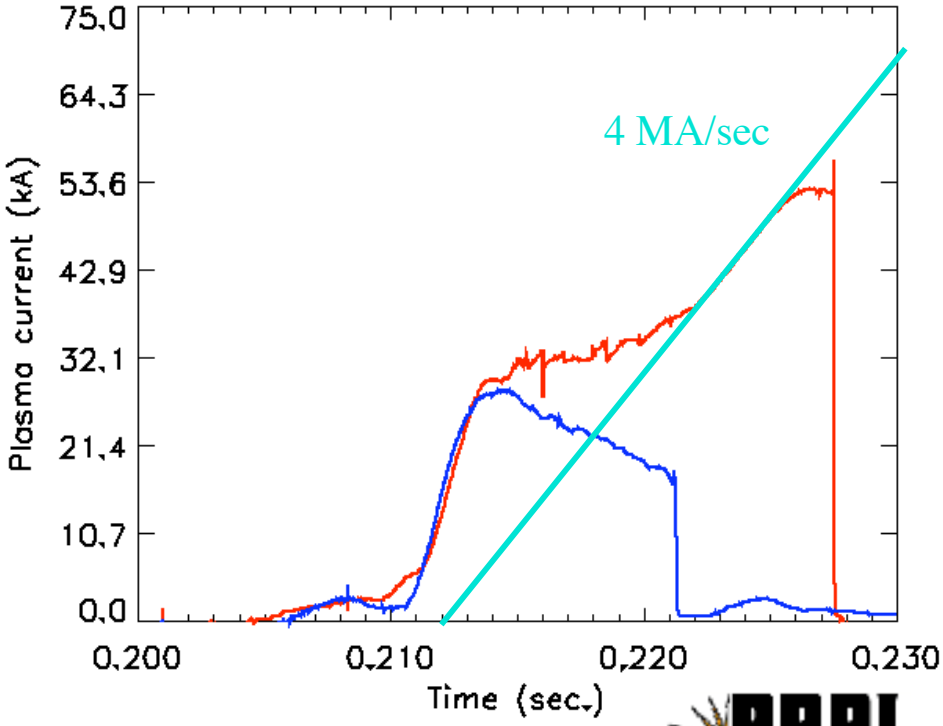
- **First run day - Lithium was mechanically stable (again)**
- Modified ohmic circuit to produce lower loop voltage.
- Current ramps at 4 MA/sec with V_{loop} <1.5 V
- *NSTX* requires 2V to ramp the current at this rate

Lithium discharge and pre-lithium discharge





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Lithium shots exhibit far more efficient loop voltage utilization (continued)

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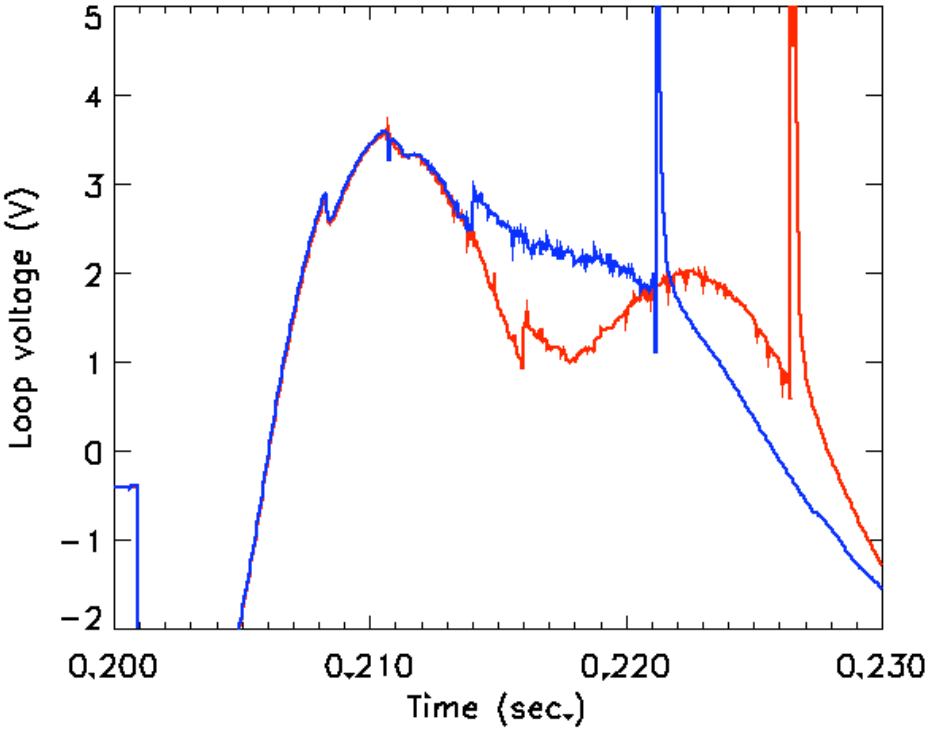
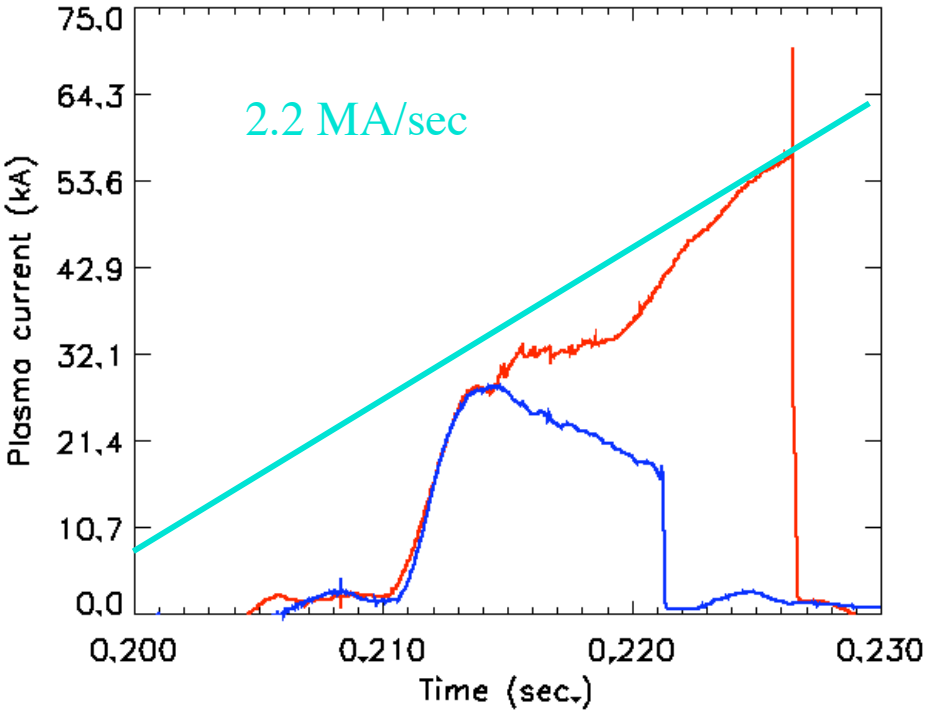
- Current ramps at 2.2 MA/sec with $V_{loop} < 1$ V
- Indicates broad current channel, very low Z_{eff}
- *Very* desirable for NSTX
- Small tokamaks have never previously operated at such low loop voltage





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Lithium shots exhibit a factor of 2-3 increase in ion temperature

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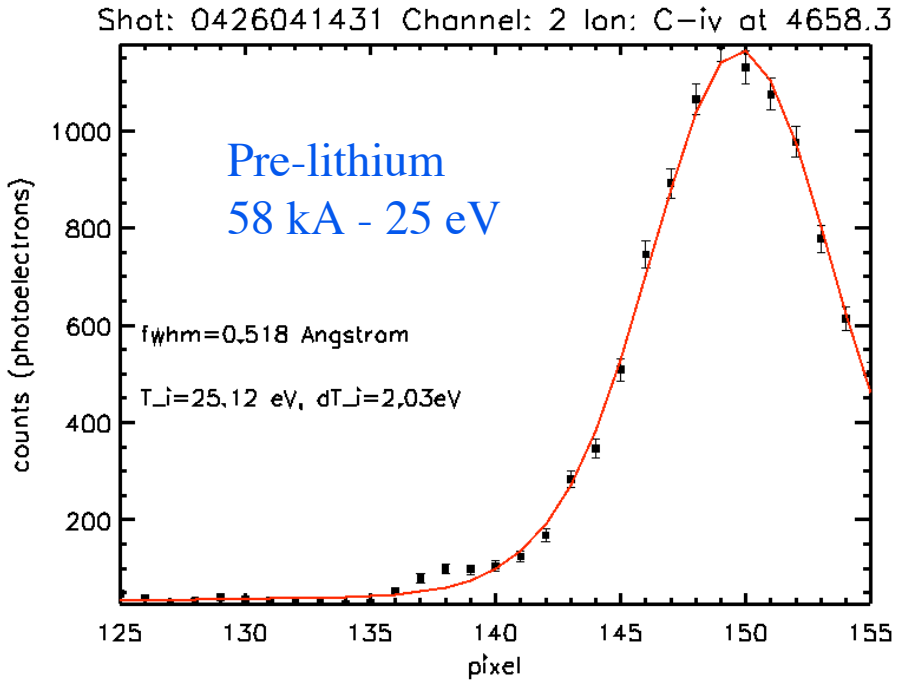
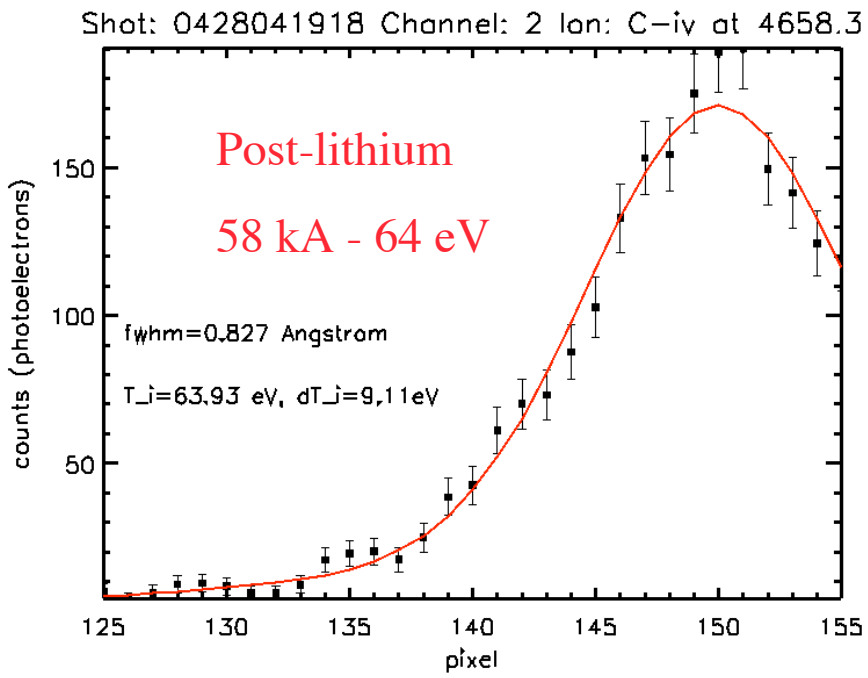
- Spectroscopic determination of ion temperature from CIV line broadening.





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Status and plans for the tray experiments

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- Presently attempting to remove enough lithium (via glow) from the interferometer windows to allow 140 GHz through.
  - Upper window was coated in <1.5 hours due, apparently, to an unrecorded temperature excursion.
  - Similar to the wall coatings produced in December 2001.
    - » That event did not disable the interferometer.
- Alternative is to modify the interferometer to use a single midplane port
  - Bounce the beam off the centerstack
  - Similar system in use on NSTX
- Run objectives:
  - Equilibrium reconstruction
  - Initial check of rf heating in a lithium tokamak
    - » LTX issue
  - Particle confinement time measurement
  - Recycling estimates
    - » D_α measurements local to the lithium
    - » Fueling studies for global estimates

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Post-tray experiments

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- We do not envision a continuation of the tray experiments past the end of June
  - Depends on the results!
- Next phase - coated poloidal limiter
  - NSTX phase I tests
- Presently looking at *resistively heated* lithium evaporation sources
  - Simpler than an e-beam source (in principle)
  - Encountering unanticipated problems; more later
- We need to select the materials for the limiter. Candidates:
  - Graphite (NSTX request).
    - » Not optimistic about the recycling results for this system.
  - Moly or tungsten sprayed graphite.
    - » Will lithium adhere to tungsten?
  - Will test explosively bonded stainless steel on copper for LTX also.

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After the tray: tests of coated limiters for NSTX, LTX

(Summer 04)

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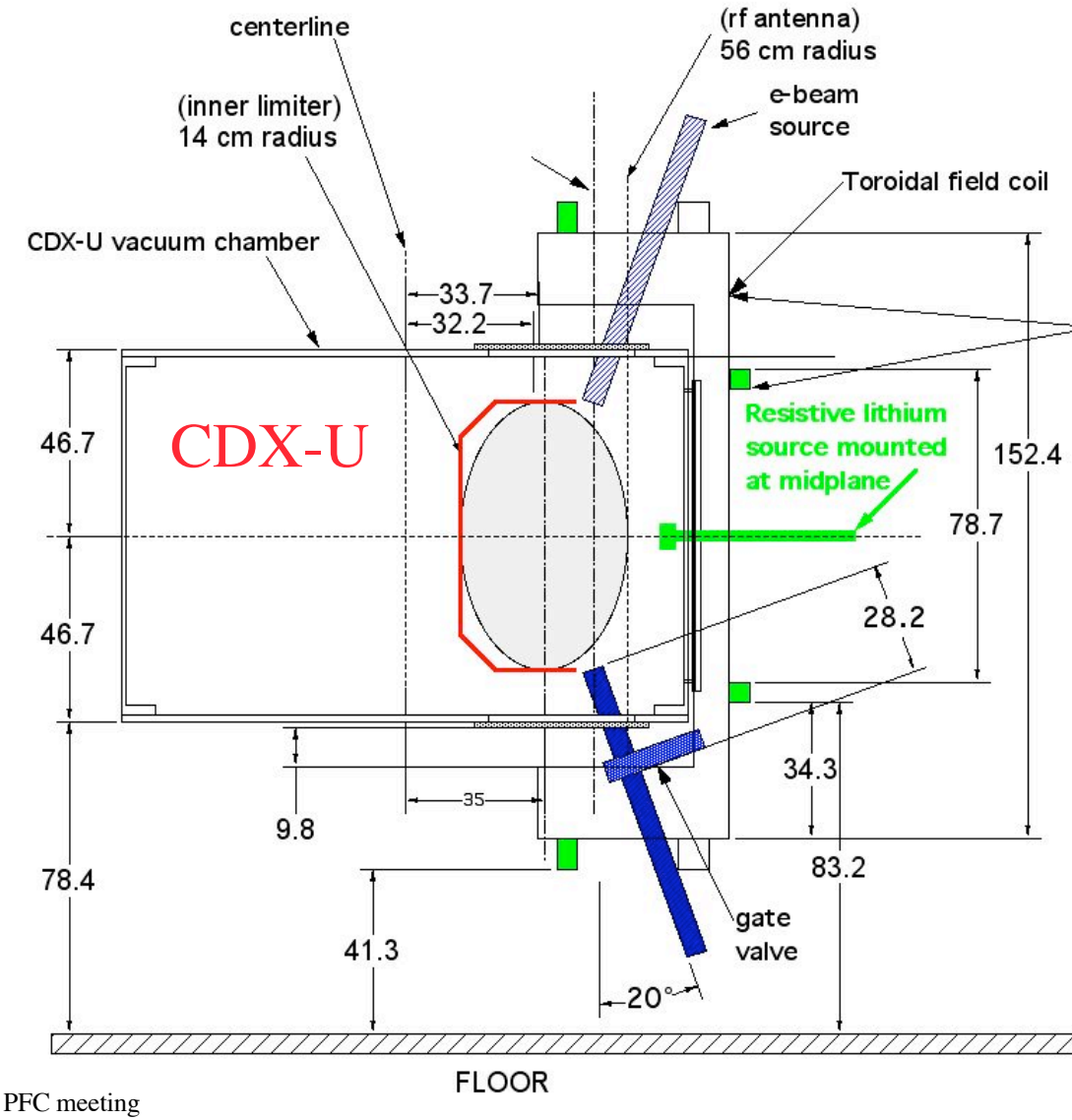

- E-beam and evaporative systems shown
  - Only use one!
- E-beam source would be nonmagnetic rebuild of existing commercial unit

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Summary

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- First lithium fill had a profound effect on the tokamak
- Second fill did too, but we won't talk about that
- Third fill is promising
  - Tray coverage is already more complete than for the first fill
  - New diagnostics, and capabilities
  - Continuing problems with window coatings
- Next phase will begin in late summer
  - Coated limiter installation
  - Coating sources are under development
  - Limiter design is in progress
- Expect to shut down for conversion to LTX early next FY.

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