

# Status of the CDX-U liquid lithium experiments

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# Outline

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- ◆ Introduction
- ◆ Tokamak status
  - Edge lithium carbide injection
- ◆ Lithium handling facility (PPPL)
- ◆ Lithium rail limiter (L3 - UCSD)
- ◆ Toroidal lithium belt limiter (PPPL)
- ◆ Diagnostics
- ◆ Schedule
- ◆ Summary

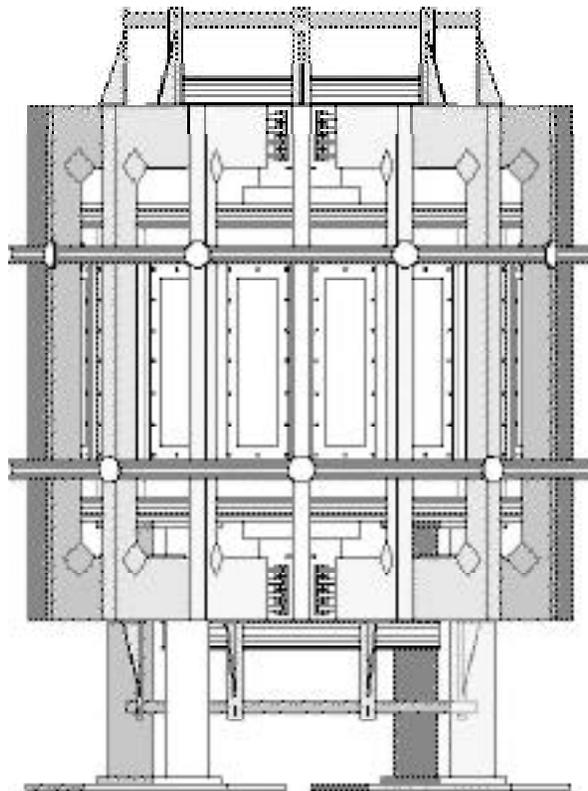
# The CDX-U liquid lithium program

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- ◆ CDX-U will soon begin to test liquid lithium systems as plasma-facing components.
- ◆ Tests will proceed in several stages:
  - Precursor experiment: lithium carbide injection for diagnostic checks, transport studies.
  - Liquid lithium rail limiter (UCSD).
    - » Toroidally local, wet mesh system.
  - Full toroidal liquid lithium belt limiter.
    - » Axisymmetric, free surface liquid tray.
  - Toroidal liquid lithium divertor target.
- ◆ Experiments will study SOL interactions, lithium influx/accumulation, changes in edge temperature & density gradients, changes in core plasma parameters, effects of MHD and disruptions, fueling effects,...

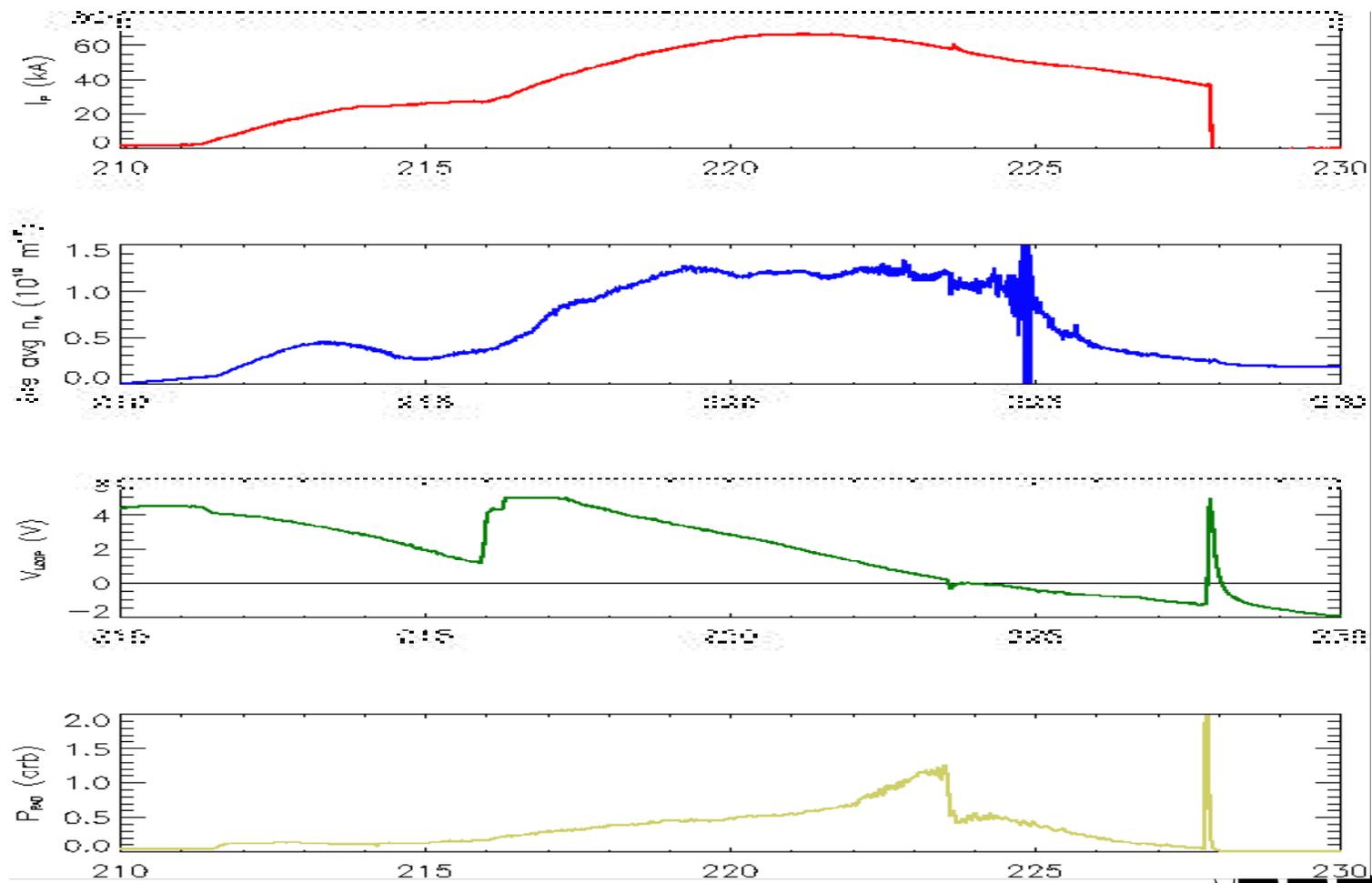
# CDX-U

- Upgrades in progress:
  - Ohmic circuit (to provide a flattop in loop voltage)
  - Position feedback system (to control strike points)
  - Lithium carbide injector (preliminary data on lithium transport)
  - Magnetics (EFIT reconstructions for modeling)



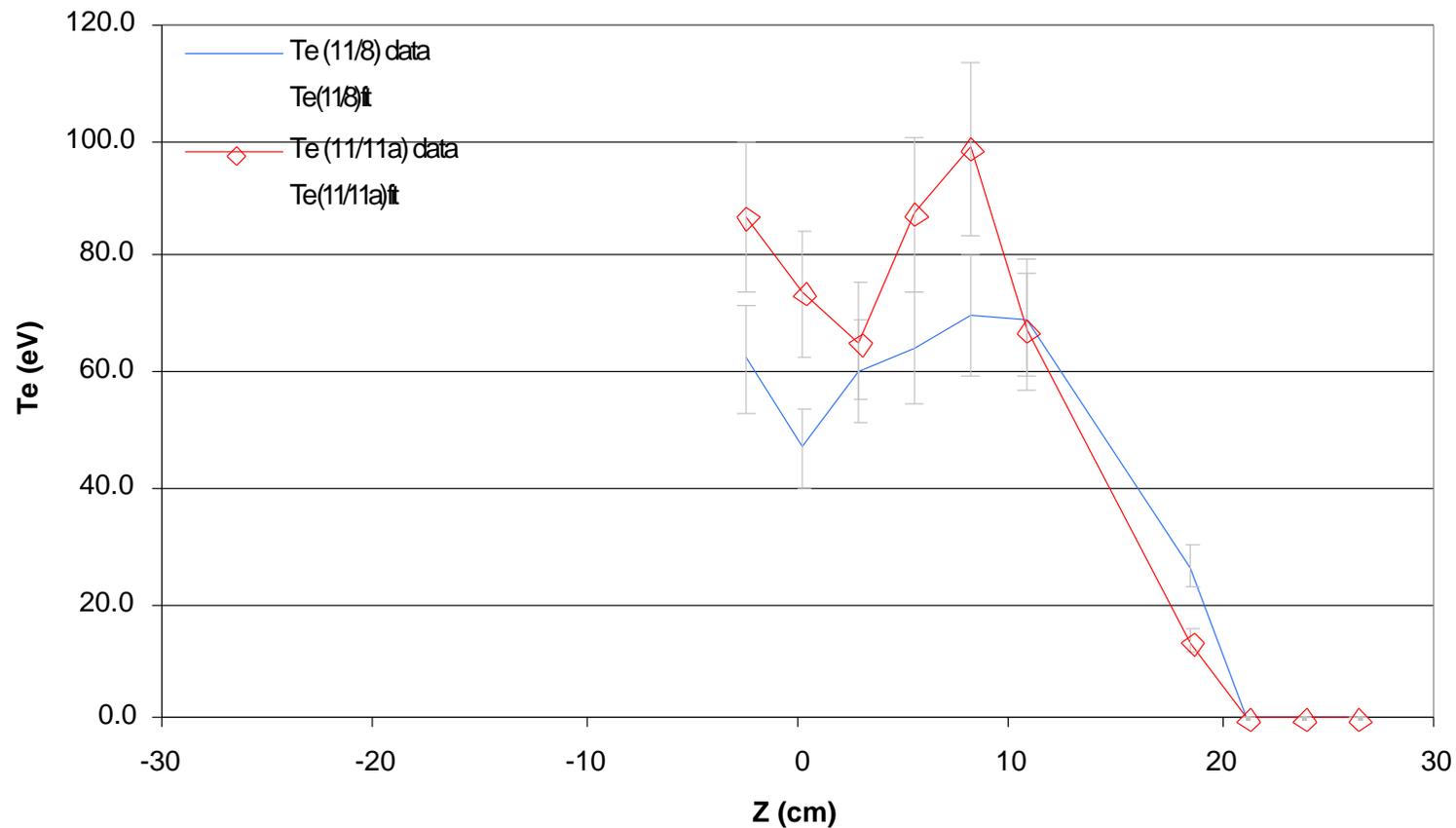
$R_0$	34 cm
$a$	22 cm
$A=R_0/a$	1.5
$k$	1.6
$B_T(0)$	2.3 kG
$I_p$	80 kA
$P_{rf}$	<200 kW
disch	<25 msec
$T_e(0)$	100 eV
$n_e(0)$	$4 \times 10^{19} \text{ m}^{-3}$

# Typical CDX-U Waveforms



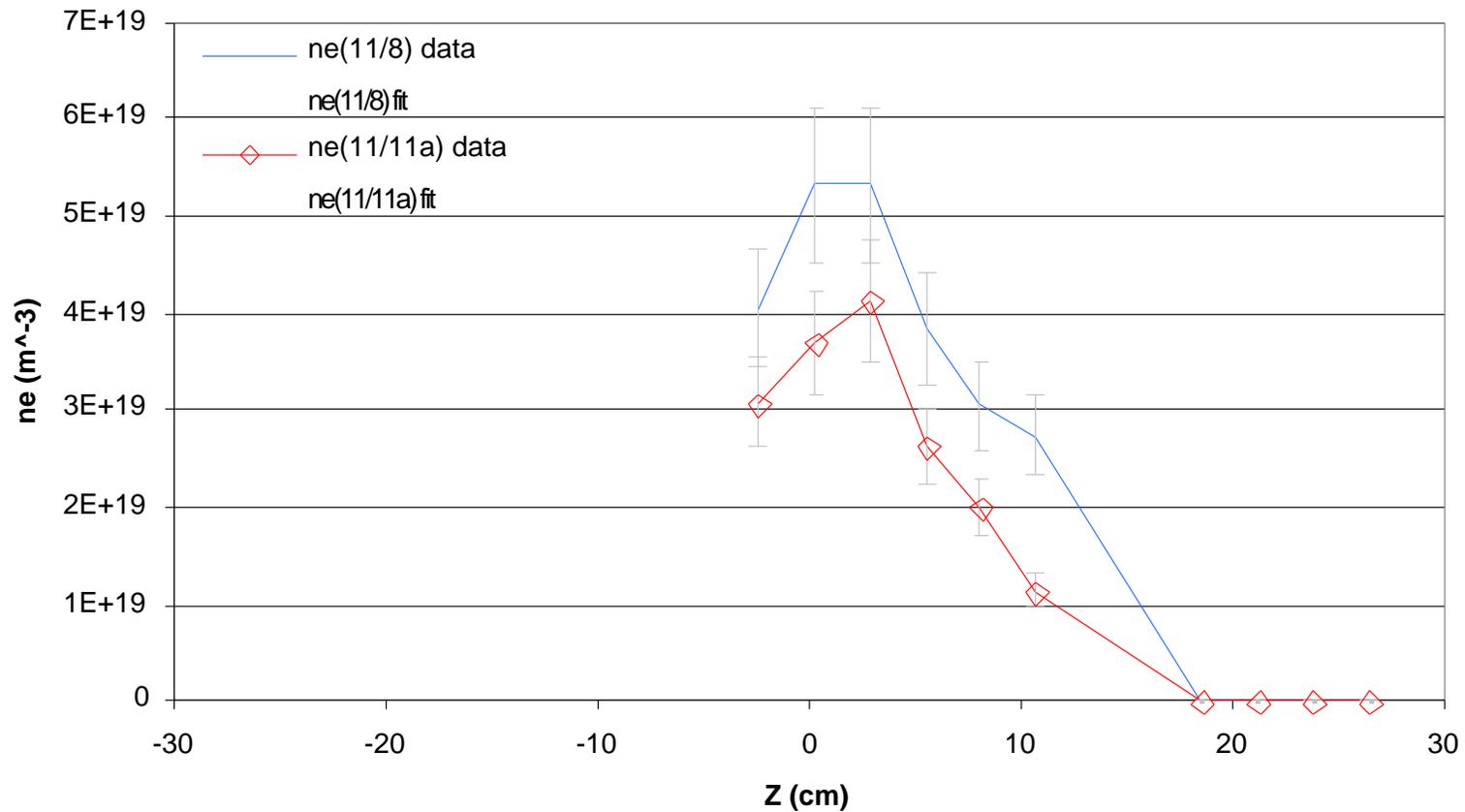
# Multipoint Thomson scattering system is now operational. Measured temperature profiles are broad, slightly hollow

Two high-density operating regimes demonstrate trade off of  $T_e$  and  $n_e$  (fixed  $V_{loop}$ )



*T. Munsat*

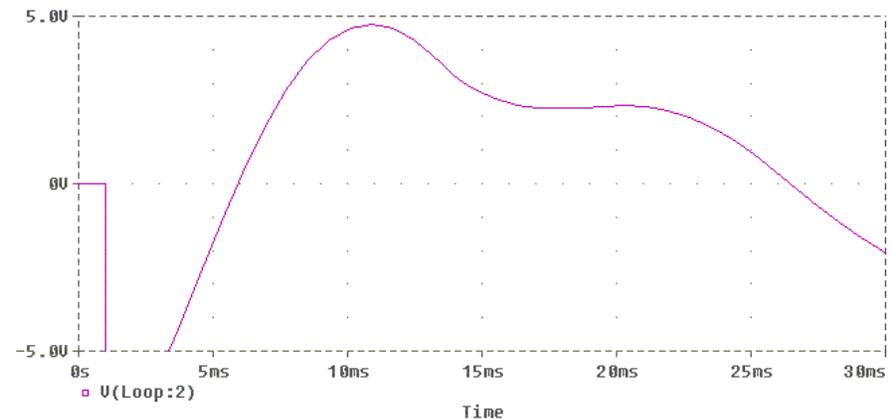
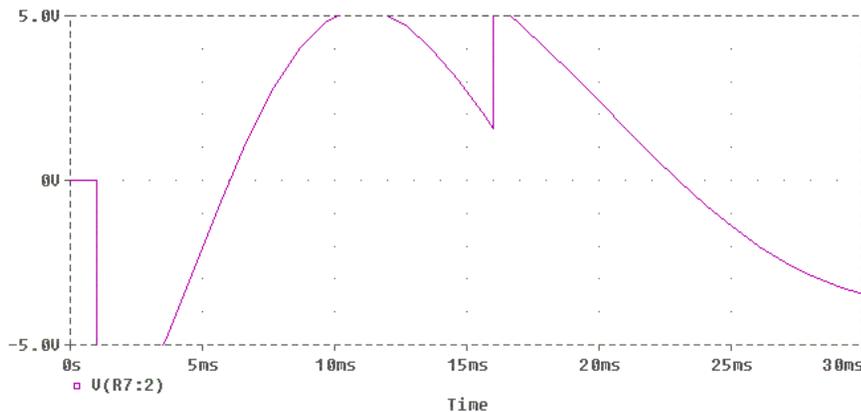
# Density profiles are highly peaked



*T. Munsat*

# Ohmic system has been modified to provide a loop voltage flattop to improve plasma control

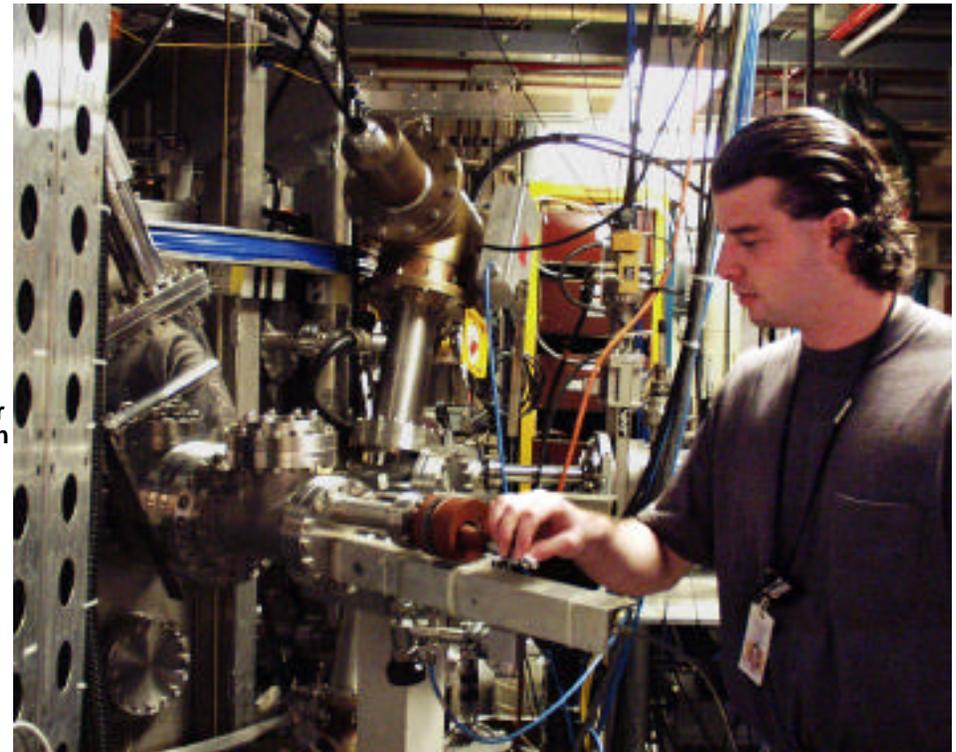
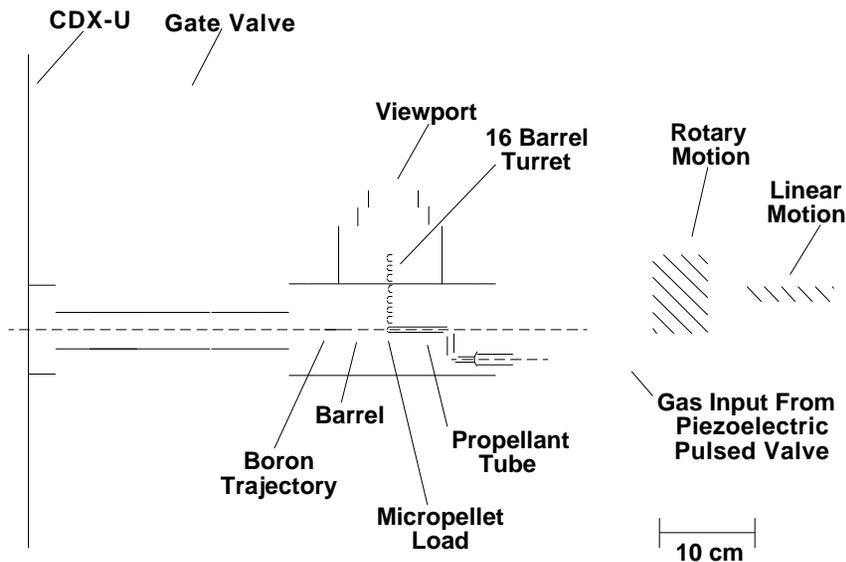
- ◆ Old waveform produces very high, rapidly varying loop voltage
  - No relaxation in the current profile
  - No steady state
  - Hard to hold the plasma strike points fixed
- ◆ New waveform designed for a ~5 msec flattop in the loop voltage
  - Allows current profile to relax
  - Easier to preprogram vertical field to fix strike point
- ◆ Position feed back possible
  - Have a “free” DSP-based feed back system which we are implementing.



Ohmic circuit modeling

# Lithium carbide ( $\text{Li}_2\text{C}_2$ ) micropellet injection will yield data on lithium transport into the core plasma

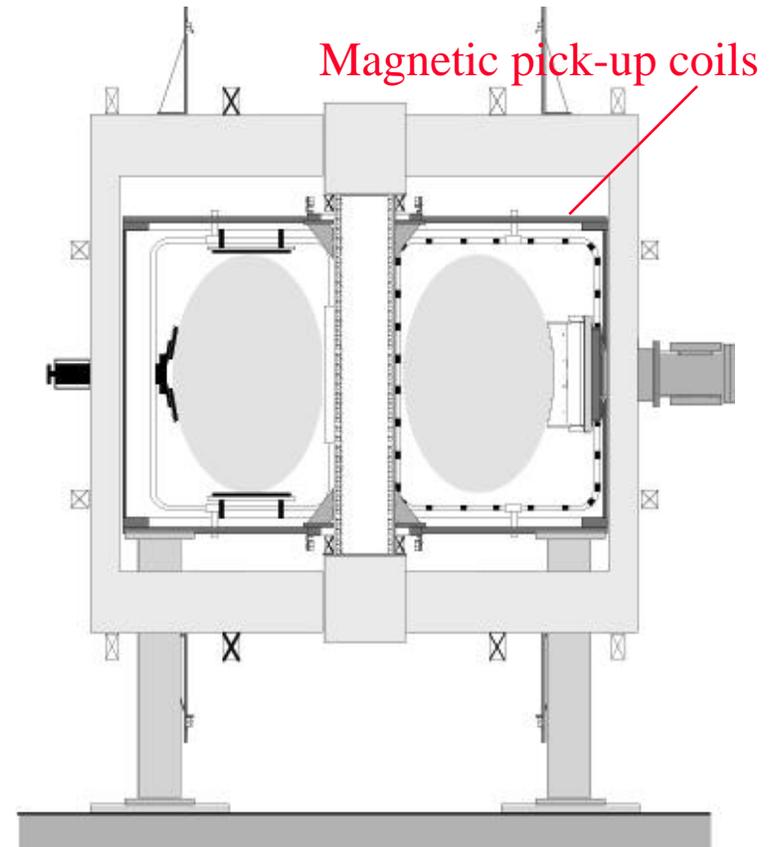
- ◆ Particle size is  $\sim 100 - 1000 \mu$
- ◆ Driver: 40 PSI deuterium
- ◆ Smaller particles arrive at the plasma first, disassociate, ionize, and are transported to the core



# Reconstruction of CDX equilibria with EFIT for modeling may require installation of additional flux loops

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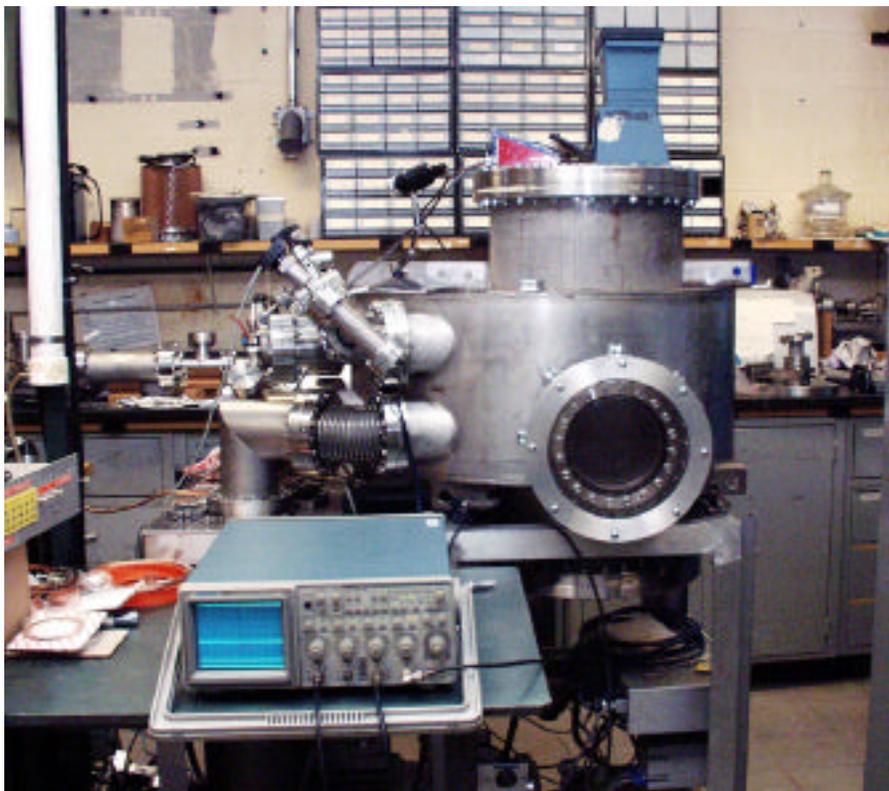
- ◆ No outer flux loops at present.
- ◆ Magnetics sensitive to wall currents.



# Lithium handling facility is nearly complete

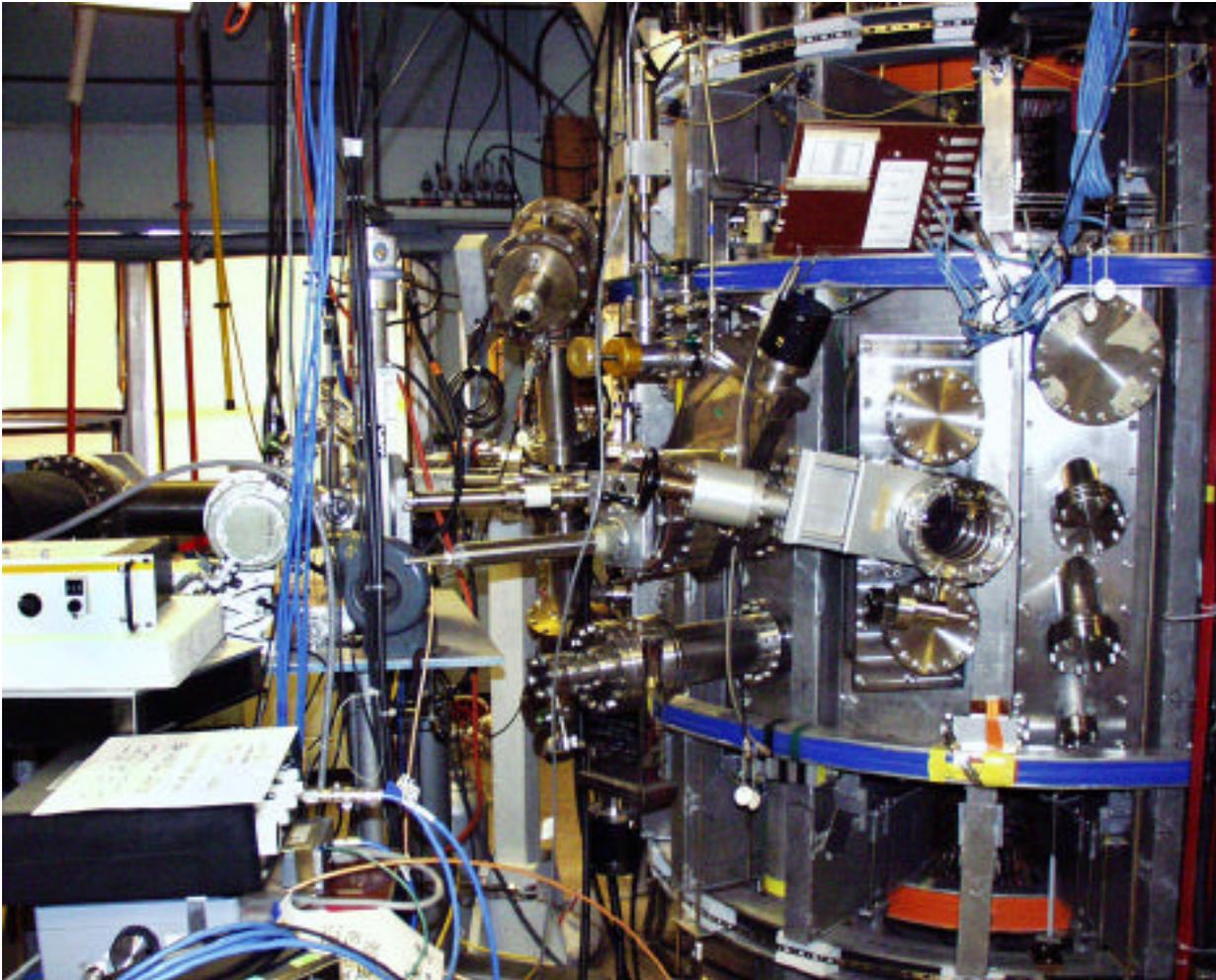
ES&H approvals in process

- ◆ Test chamber has already been used to test reproducibility, timing of lithium carbide injector.
- ◆ Glove box arrived recently; room is being readied.



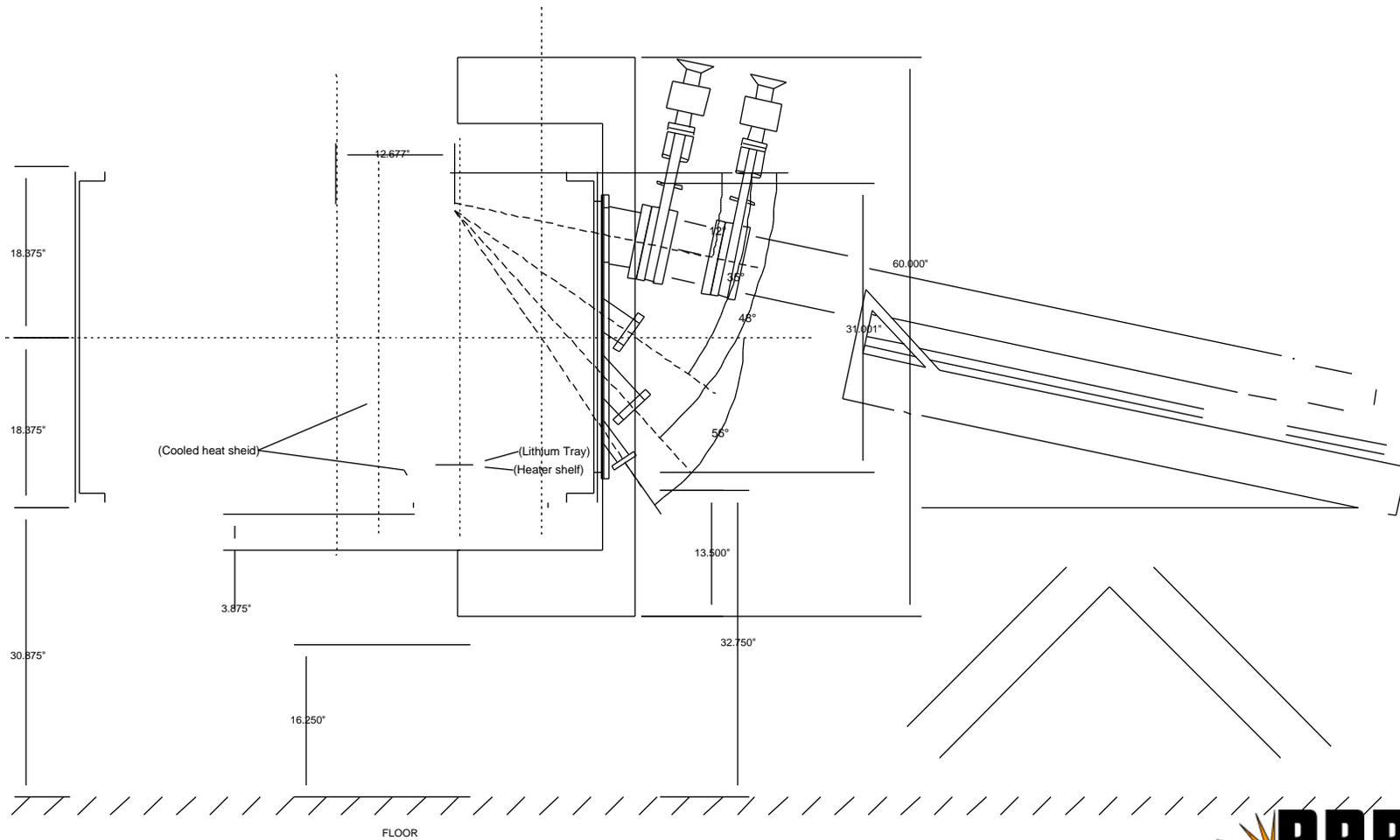
# Modifications to CDX-U porting to accommodate UCSD rail limiter complete

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- ◆ Gate valves will be installed during final limiter alignment in June.
  - One visible, one IR window to be installed on gate valves.
- ◆ ES&H documentation in process
  - INEL assisting with failure mode analysis.
  - Much useful advice from ANL, UCSD, SNL.
- ◆ Final design review scheduled for May 17.

# Rail limiter will remain in CDX after the toroidal belt limiter is installed



## Toroidal lithium belt limiter is in design stage

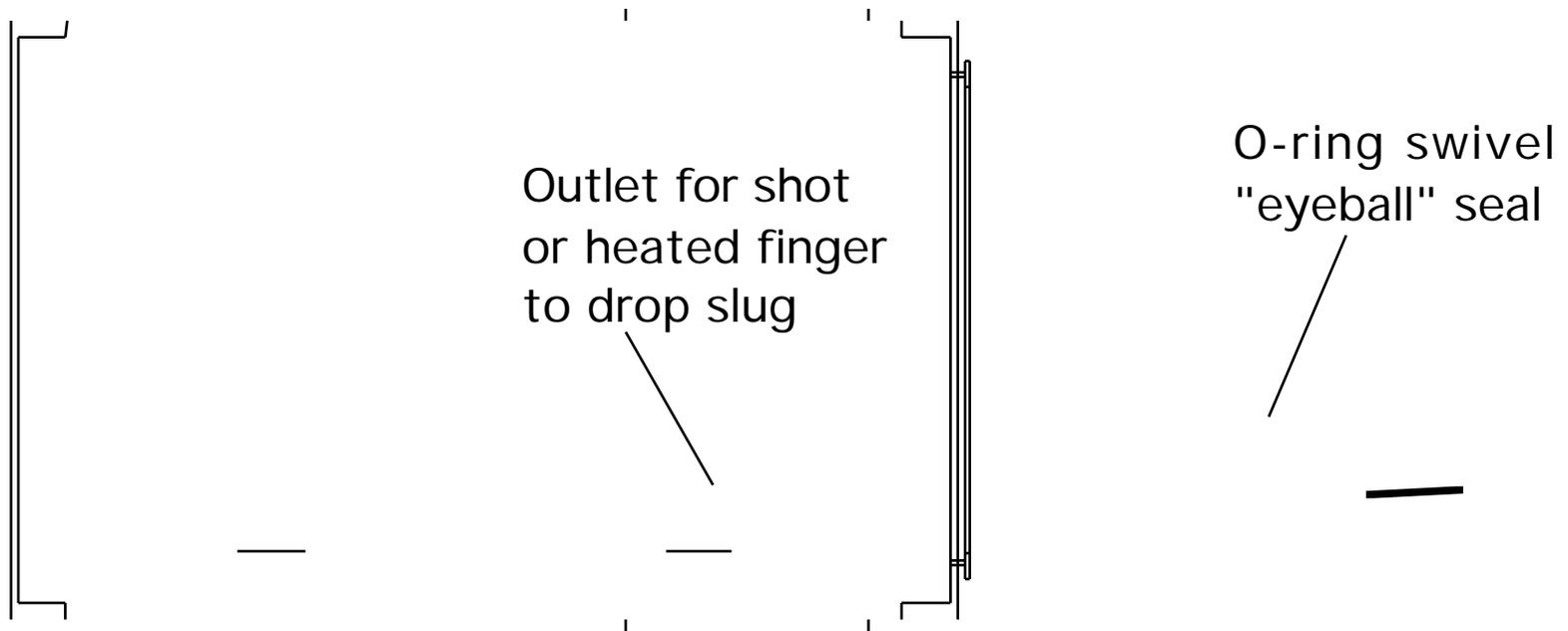
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- ◆ Conceptual design review held 4/11. Lots of suggestions!
- ◆ Baseline design now a two-section bolted tray with shallow (few mm) layer of lithium.
- ◆ Tray will rest on tubular heaters.
- ◆ After installation, CDX will be pumped; lithium solid loaded under vacuum.
- ◆ At end-of-life of tray (or lithium fill), CDX vented to argon and tray disassembled.
  - Removed through glove bag/PVC tube.

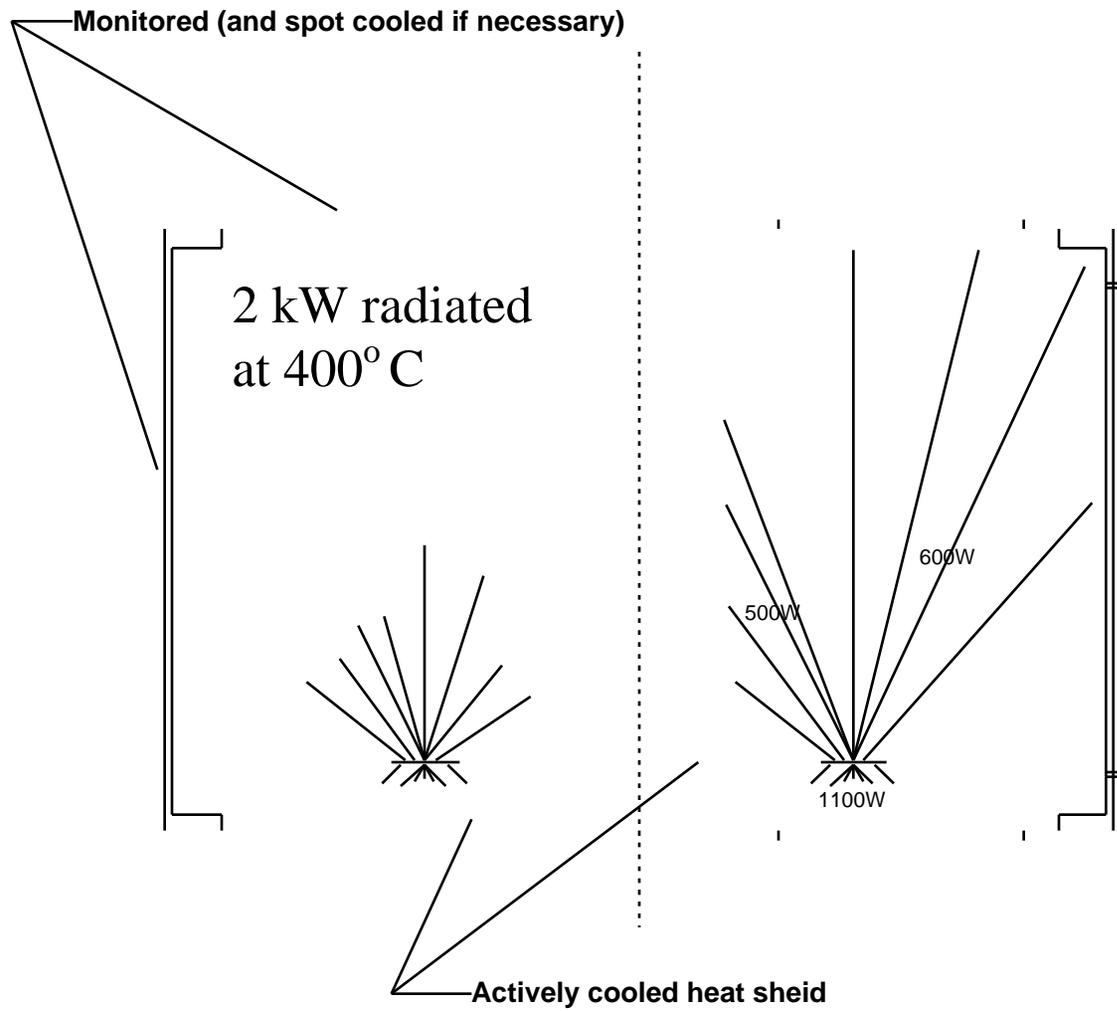
# Tray will be loaded with lithium shot or slugs under vacuum

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- ◆ Lithium will be loaded at several toroidal locations.
  - Only a small area behind the center stack is inaccessible from a single loader location.



# Silicone cooled shroud will be installed

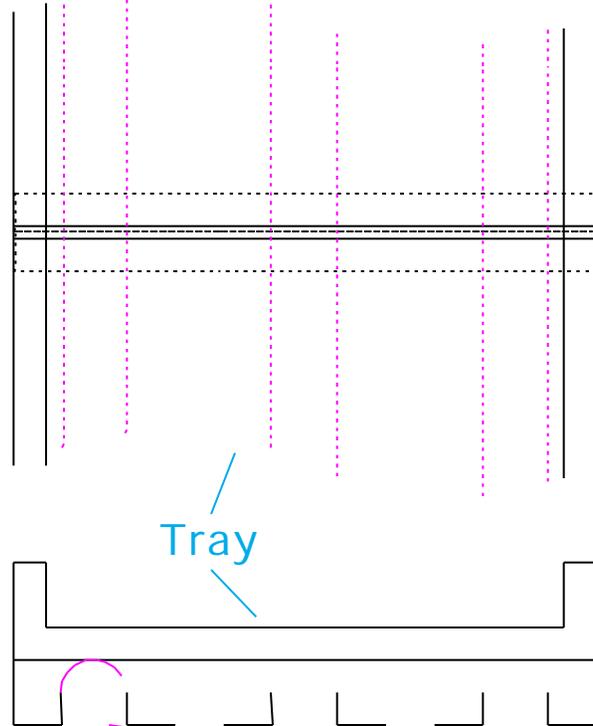


- ◆ Center stack is 0.060” Inconel with welded SS bolting fixtures.
- ◆ Only cooling is thermal transfer to the water-cooled ohmic coil (in air!) through epoxy potting.
- ◆ Lower flange is o-ring sealed at outer perimeter.
- ◆ Cooled shroud necessary to avoid thermal problems.

# Joint design for tray under study

- ◆ Tray will be annealed under weight for stress relief, to minimize warping.
- ◆ Joints will be bolted with molybdenum screws, stainless nuts.
- ◆ Tantalum seal at joints may be used, if needed.

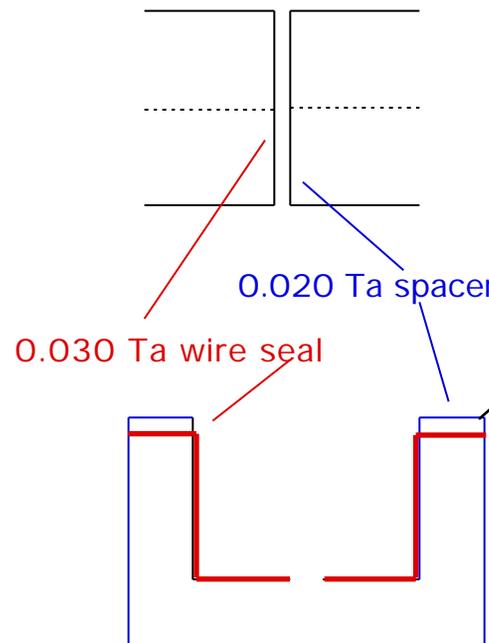
Bolting flange



Tray

Guide

Tubular heaters



0.020 Ta spacer

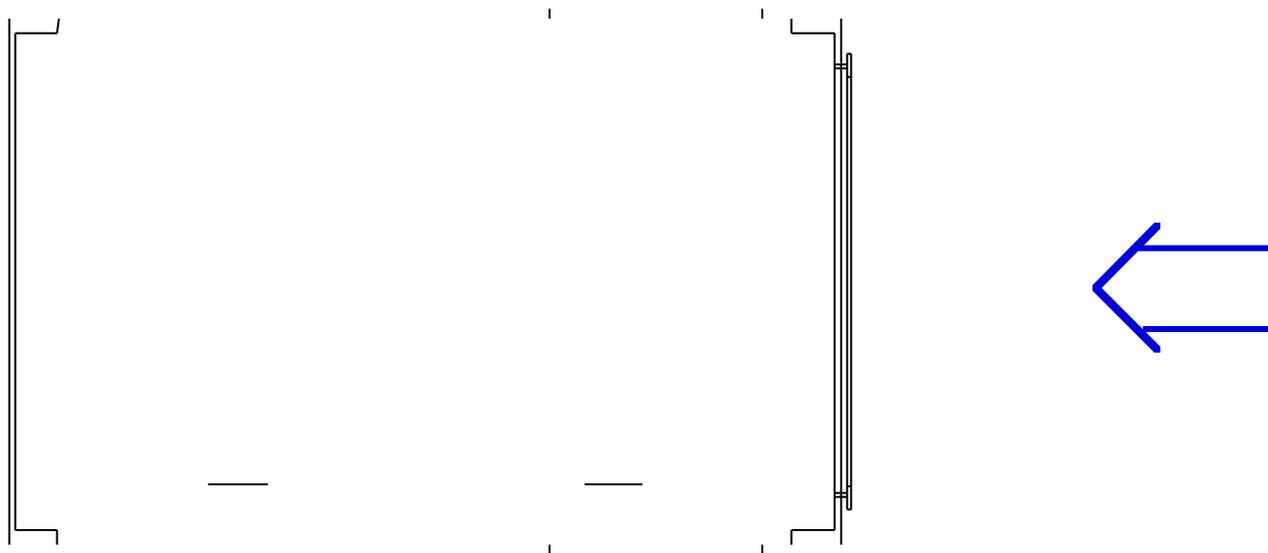
0.030 Ta wire seal

Seal spot welded  
to spacer here

## Tray will be unbolted, removed while under argon.

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- ◆ Outer flange will be removed, bag taped off.
- ◆ Second bag applied, original bag removed.
- ◆ Tray disassembled, removed within second bag, taped off.
  - Tray rests on rails; may be rotated within vessel.
  - Disassembly involves removal of ~10 screws holding halves together.
- ◆ Tray transferred to sealed container.

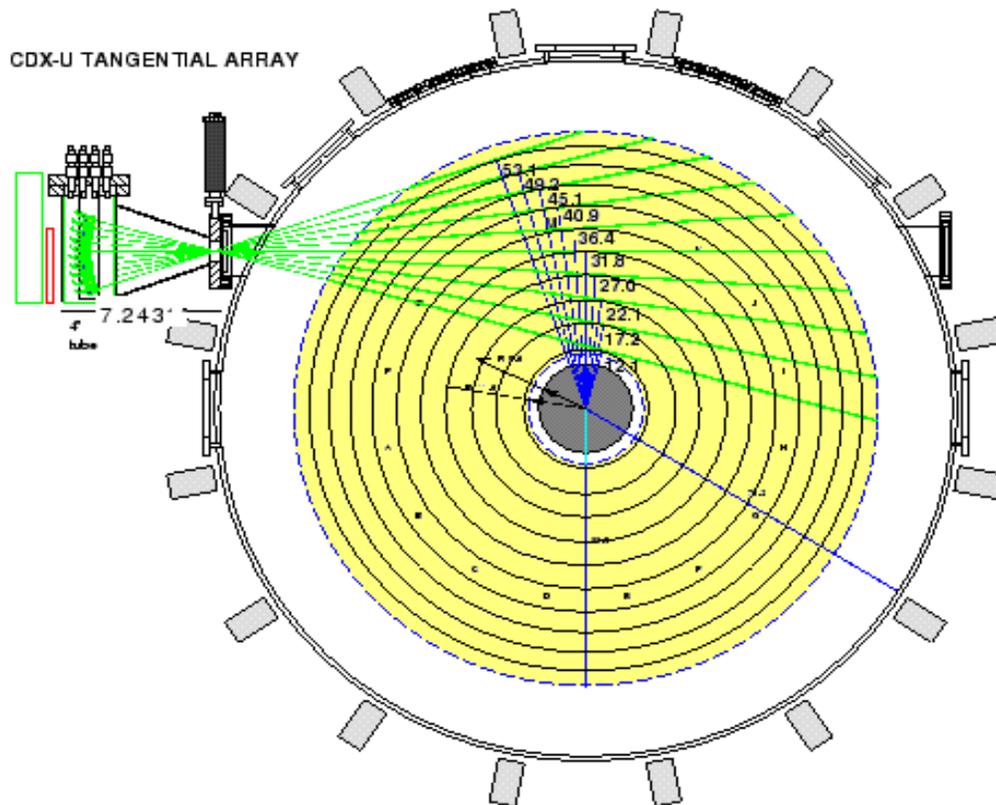


# Lithium specific diagnostics

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- ◆ Bolometer and ultrasoft x-ray arrays now operational (JHU).
  - USXR array utilizes multilayer mirrors. Test mirror set images oxygen.
  - Mirrors for Li III line (130 Å) are in-hand.
  - Remachined mounts, mirrors will be installed prior to installation of UCSD rail limiter.
- ◆ Sightlines for the rail limiter include visible, IR.
  - Visible for fast camera, ORNL filterscope array to monitor lithium, other impurity lines at limiter.
  - IR window for SNL camera.
- ◆ Several gate valves will be dedicated to sample coupons (SNL).
  - In vessel coupons rendered useless by vessel passivation procedure.
  - Coupons transferred out of CDX under vacuum, shipped in argon.
- ◆ New 8 tip Langmuir “rake” probe under construction for edge profiles.

# A tangential bolometer array is now operational on CDX-U XUV array (AXUV diodes from IRD)



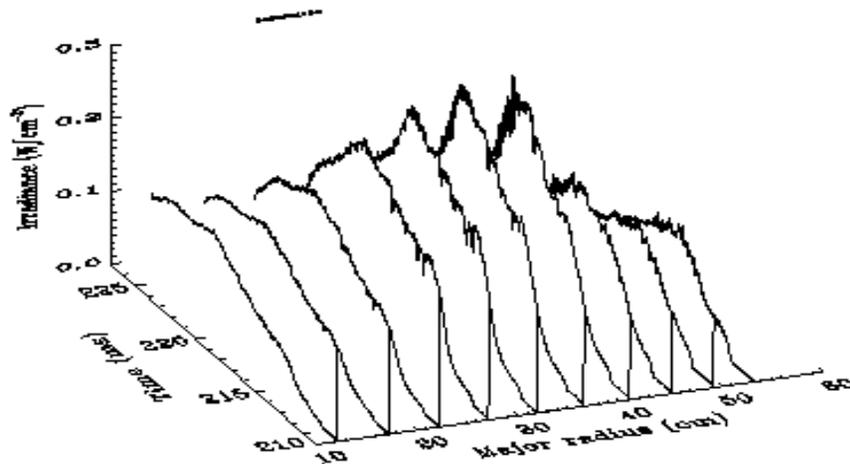
V. Soukhanovskii,  
D. Stutman, M. Finkenthal,  
M. Iovea, [Johns Hopkins University](#)

- **Two modes of operation:** bolometric (diodes only) and filtered (2500 Å Be and 3000 Å Ti filters)
- Filtered mode enables mapping of O VI or C V emissivities
- 50 kHz  $10^5$  gain custom-made pre-amplifiers in bolometer mode, 180 kHz  $10^7$  gain pre-amplifiers in filtered mode
- 10 channels, tangential view with full coverage of plasma (within  $q \leq 4-5$ )
- DAQ: standard 8210 CAMAC digitizers, GPIB, 350 MHz PC running LabView

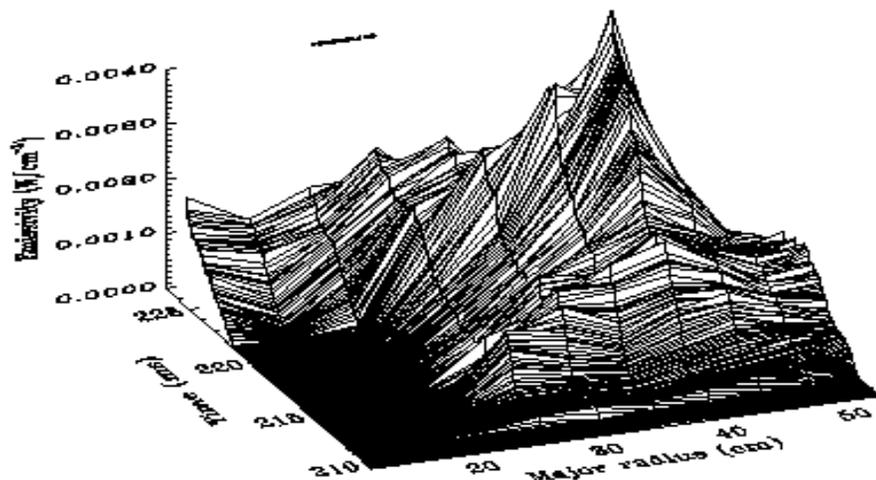


# Radiation losses are highly peaked

XUV array data (bolometer mode)  



Chord integrated and inverted emissivity from the array in bolometer mode.



V. Soukhanovskii,  
D. Stutman, M. Finkenthal,  
M. Iovea, [Johns Hopkins University](#)

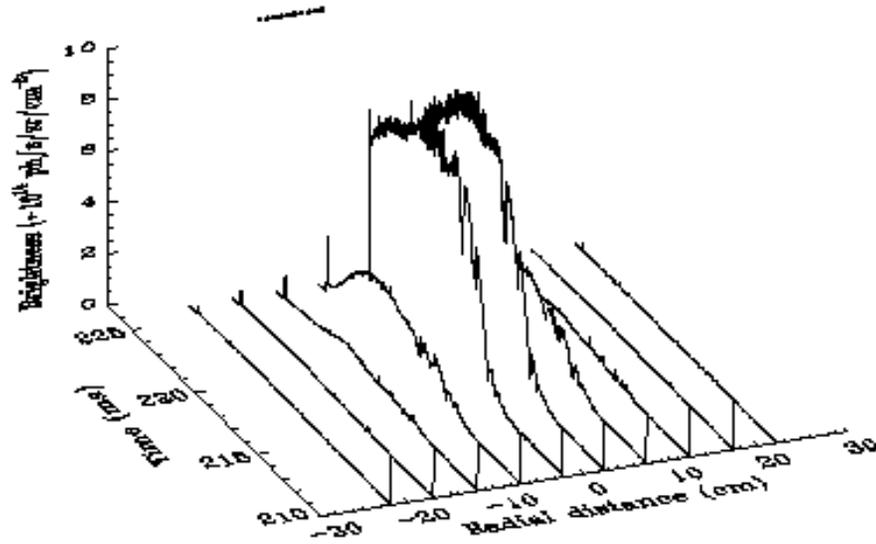
Chord-integrated bottomness (top) and inverted emissivity (bottom).

# Multilayer mirror array for ultrasoft x-rays (JHU)

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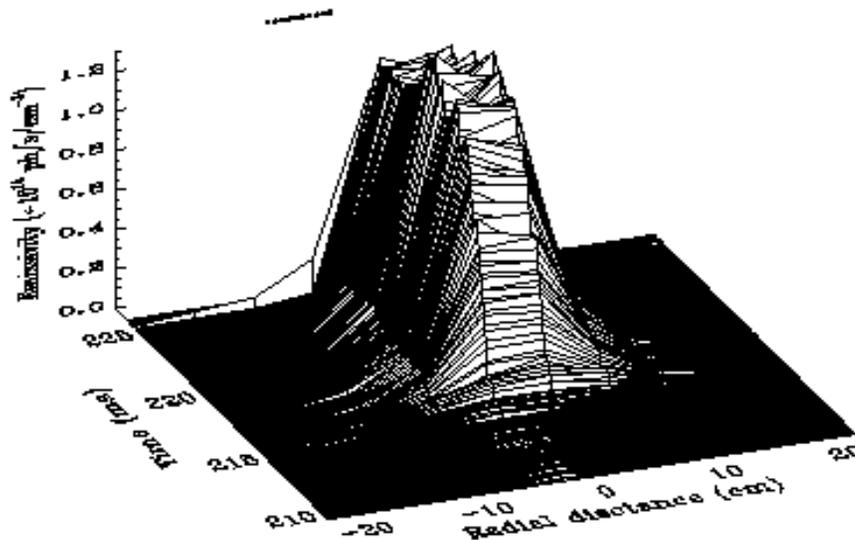
# O VI emissivity profiles

## Results indicate core impurity accumulation in CDX-U discharges



MLM array chord-integrated and inverted O VI  $\lambda 150$  emissivity

⇒ Correlates with Thomson results



V. Soukhanovskii,  
D. Stutman, M. Finkenthal,  
M. Iovea, [Johns Hopkins University](#)

MLM array chord-integrated brightnesses (top) and inverted O VI  $\lambda 150$  emissivity (bottom)

# Schedule

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- ◆ UCSD rail limiter to arrive at beginning of next month.
  - Final design review next week.
  - Final assembly (welded bellows) at PPPL.
- ◆ Limiter to be loaded, installed in June.
  - Operations with rail limiter to continue into August.
- ◆ Rail limiter will be gated off during installation of toroidal tray.
  - Preliminary design review scheduled for May 30.
  - Final design review scheduled for July 15.
- ◆ Installation tentatively scheduled for late August.
  - Dependent both on rail research schedule and tray, shroud completion.

# Summary

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- ◆ Lithium carbide injection experiments scheduled to begin this week for transport studies.
- ◆ UCSD rail limiter will be on site within a month.
- ◆ Facilities are nearly ready to begin liquid lithium experiments.
  - Design, safety reviews well along.
- ◆ Toroidal tray limiter in design.
  - Scenarios developed for tray loading, removal.
- ◆ Machine upgrades, lithium diagnostics in preparation.
- ◆ First liquid lithium limiter experiments in June!