Liquid tin sputtering experiments in the Ion-surface InterAction eXperiment

Matt Coventry, David Ruzic, & Robert Stubbers

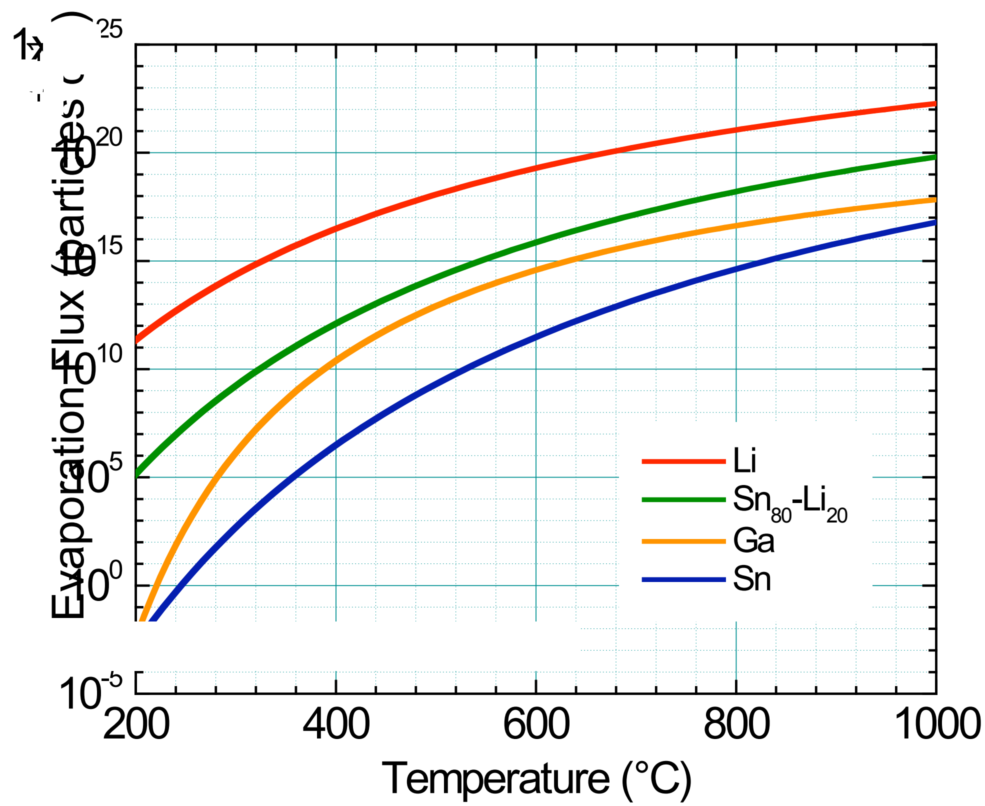
Plasma-Material Interaction Group
University of Illinois @ Urbana-Champaign

Outline

- Sn sputtering
  - Modeling
  - Experiments
- IIAX modifications/improvements
- Future work
  - Liquid sample sputtering measurements
  - Solid targets for ITER PFC support

Advantage of using liquid Sn

- Sn has an evaporative flux many *orders of magnitude* lower than Li
- Friendly & abundant (cheap!)
- Evaporation curves based on theory by [1] and fits from [2] and [3].

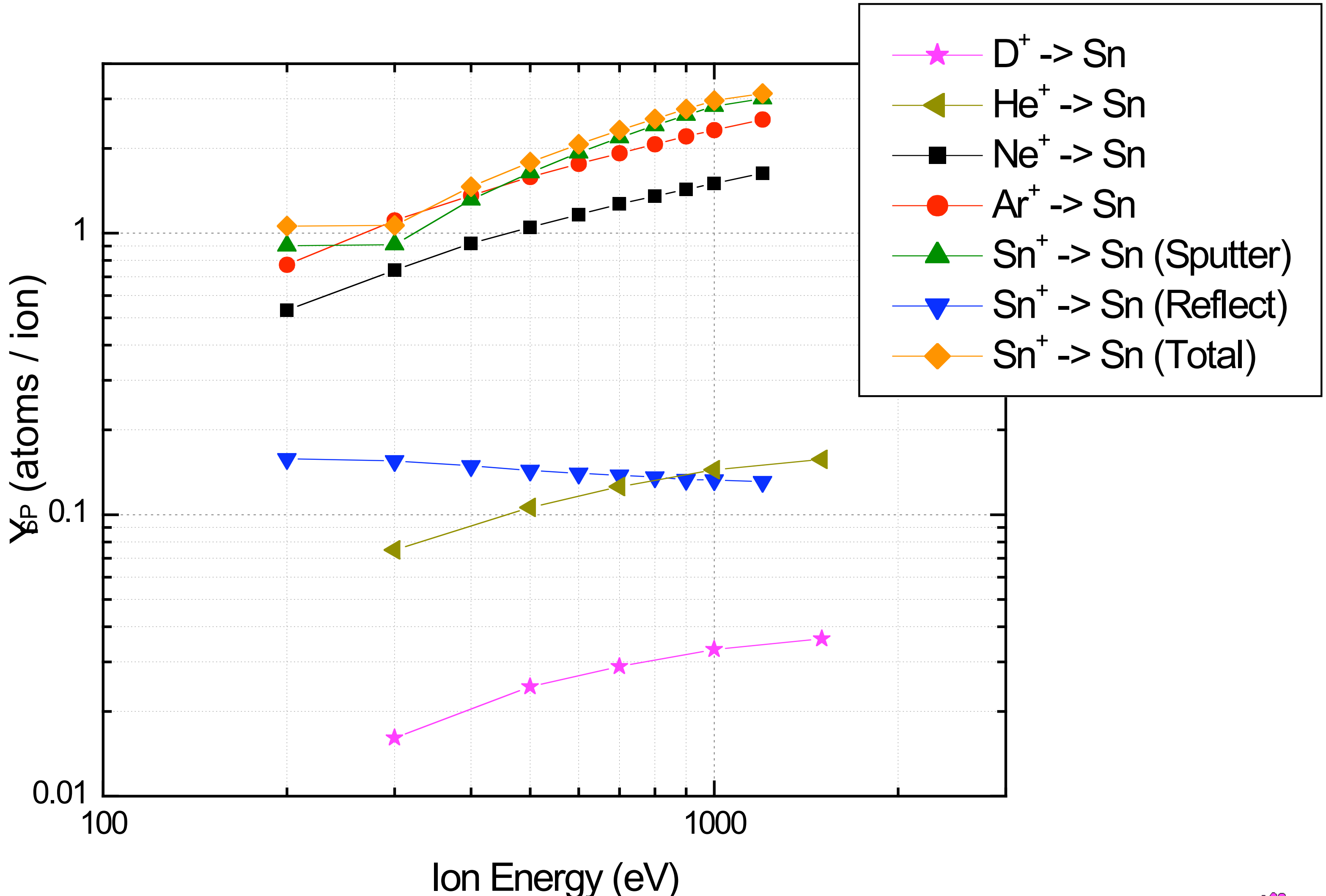


[1] Y. Waseda, S. Ueno, K.T. Jacob, J. Mat. Sci. Let, 8, (1989) 857-861.

[2] M.A. Abdou, A. Ying, N.B. Morley et al., APEX Interim Report Report No. UCLA-ENG-99-206, (1999).

[3] I.A. Sheka, I.S. Chaus, T.T. Mityureva, *The Chemistry of Gallium*, (1966), Elsevier, Amsterdam.

VFTRIM Simulation Results for 45º incidence on solid Sn

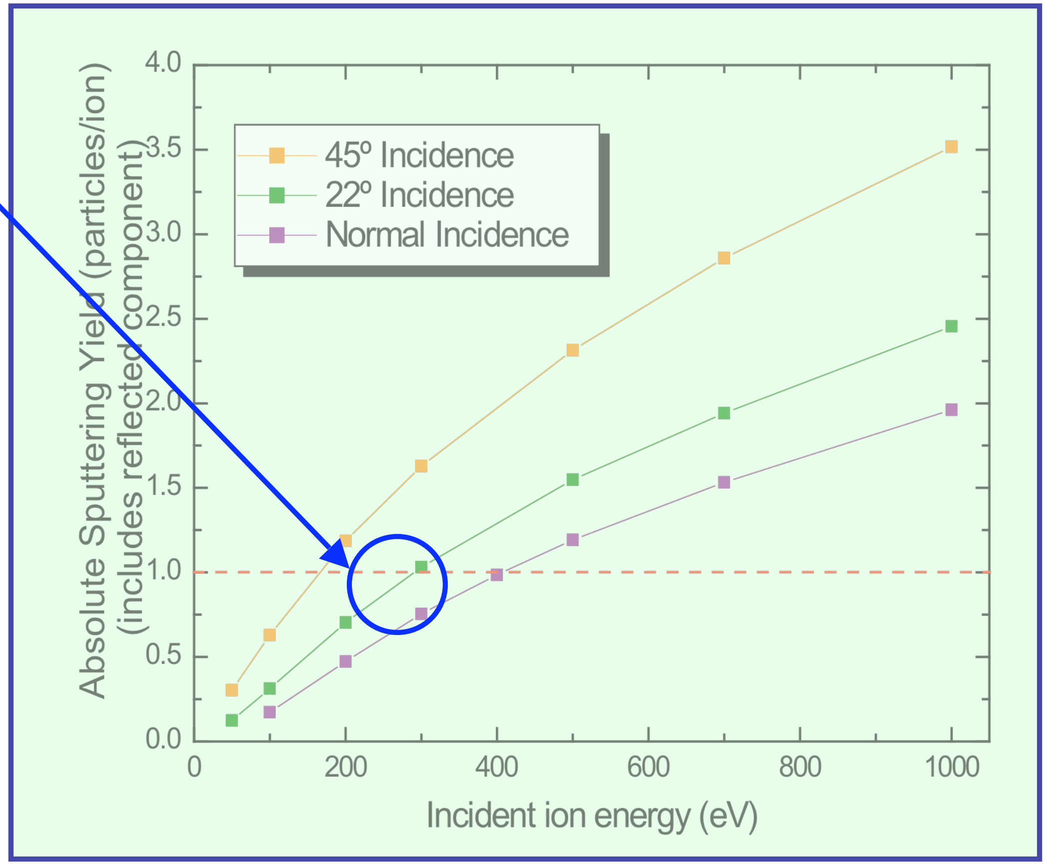


ILLINOIS

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

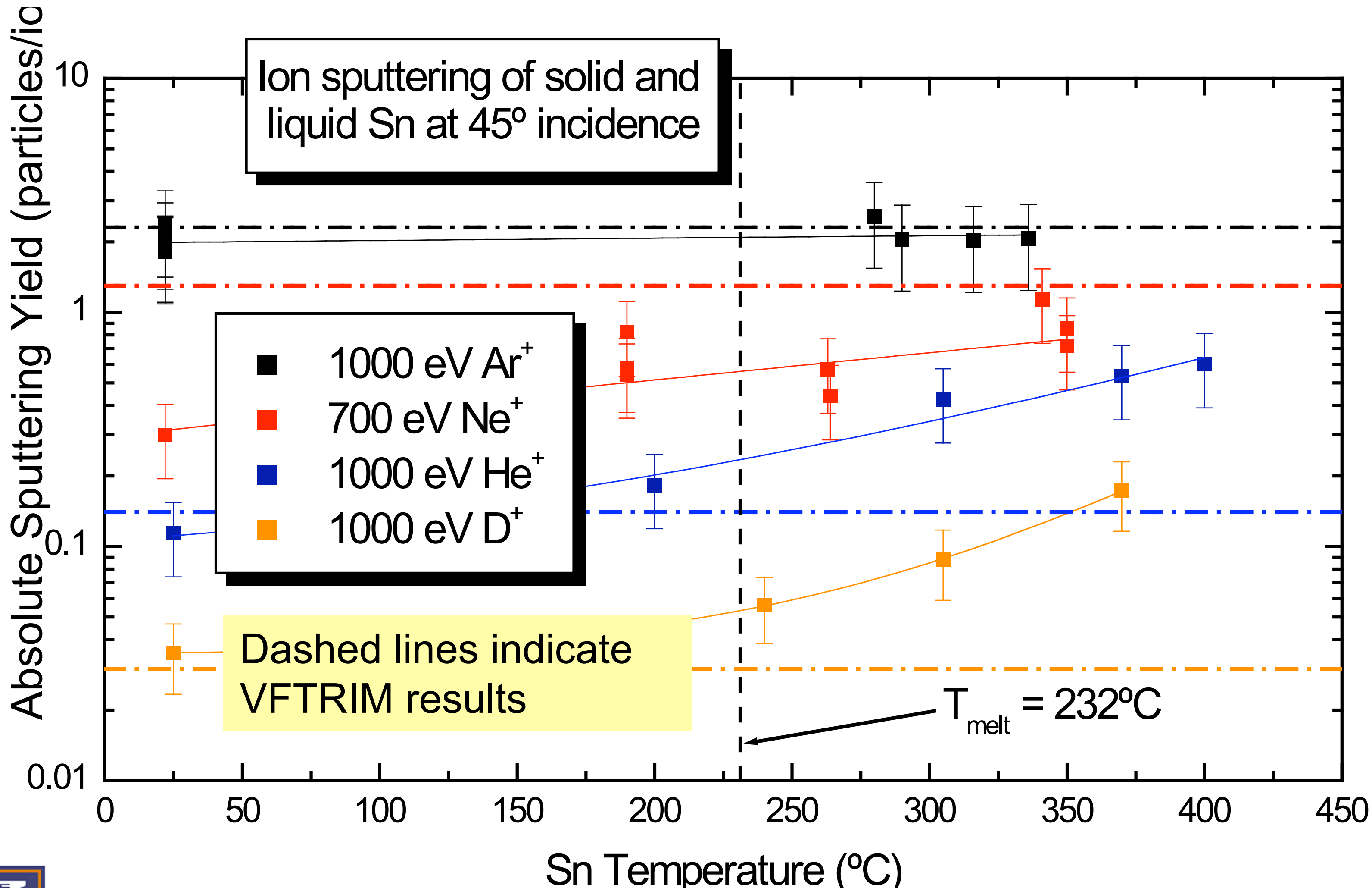
VFTRIM Simulations of Sn self-sputtering

- Sn ions are predicted to have a mean incident angle of 22º and an average energy of 270 eV [1] for an ARIES-AT configuration with a liquid Sn divertor
- Thus, equally important is the reduction from decreasing the angle of incidence
- Normal-incidence runs may be performed in the future to complement the oblique work done here
- D^+ sputtering of liquid lithium was shown to have a drastic (10 to 1000 fold) increase as a result of increasing the temperature



[1] Brooks, J.N. Fus. Eng. Des. **60** (2002) 515-526.

Sn sputtering results from 4 species

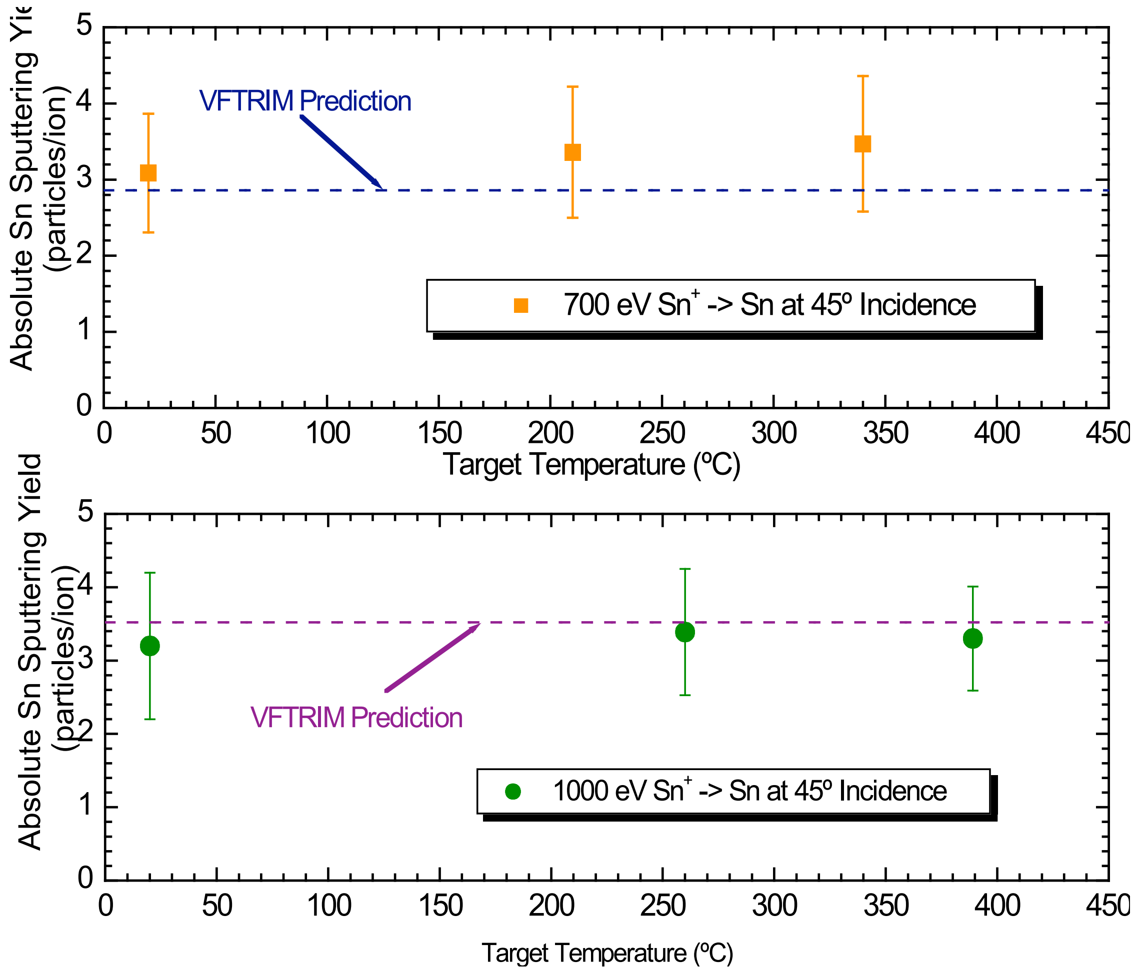


ILLINOIS 1867

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Sn self-sputtering measurements

- Early data indicate that Sn self-sputtering is also not significantly enhanced by temperature at least up to 400ºC
- These results are similar to those for both Ne^+ and Ar^+ sputtering of Sn (from a temperature enhancement perspective)
- Important to note that higher temperatures may still yet show temperature-enhanced properties



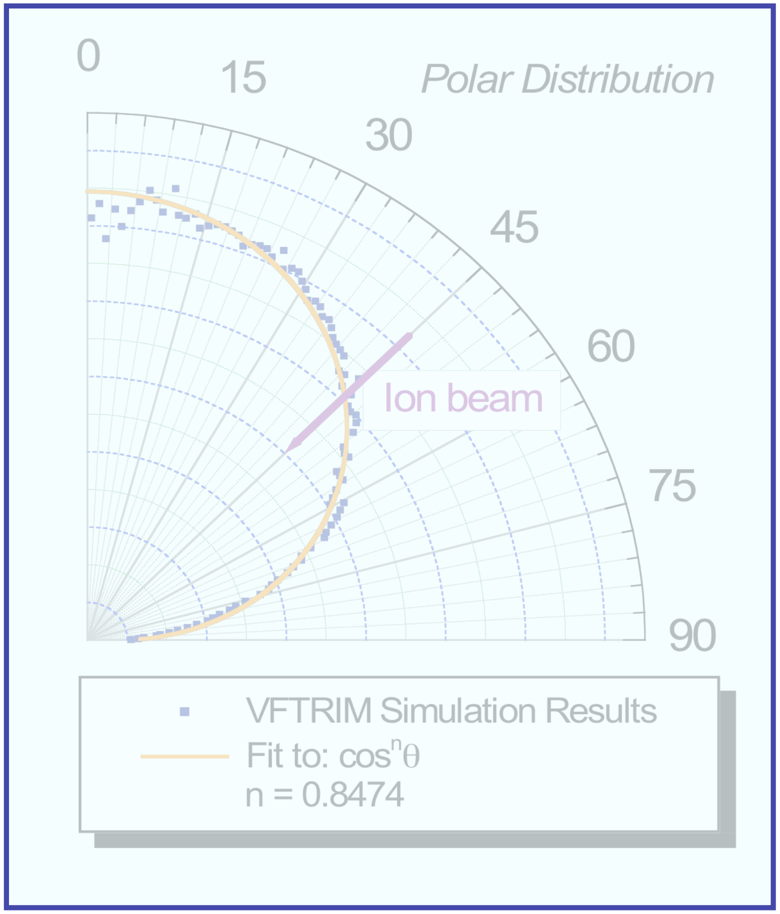
Recent improvements

- Data analysis
  - Using VFTRIM "data" of sputtered particle angular distributions to help calculate how much of the ejected material intersects our monitoring crystal
- Hardware upgrades
  - Ion beam system
    - Neutral filter
    - Vertical steering near target
  - Target and QCM system
    - High temperature ability

Improved estimate of “geometric factor”: 1

In general…

- This “geometric factor” is just an integral over the QCO crystal surface that estimates what fraction of the sputtered material strikes (but not necessarily sticks to) the crystal
- VFTRIM simulations are now performed for each ion-target combination to generate sputtered particle distribution “data” to input into the computation of this geometric factor

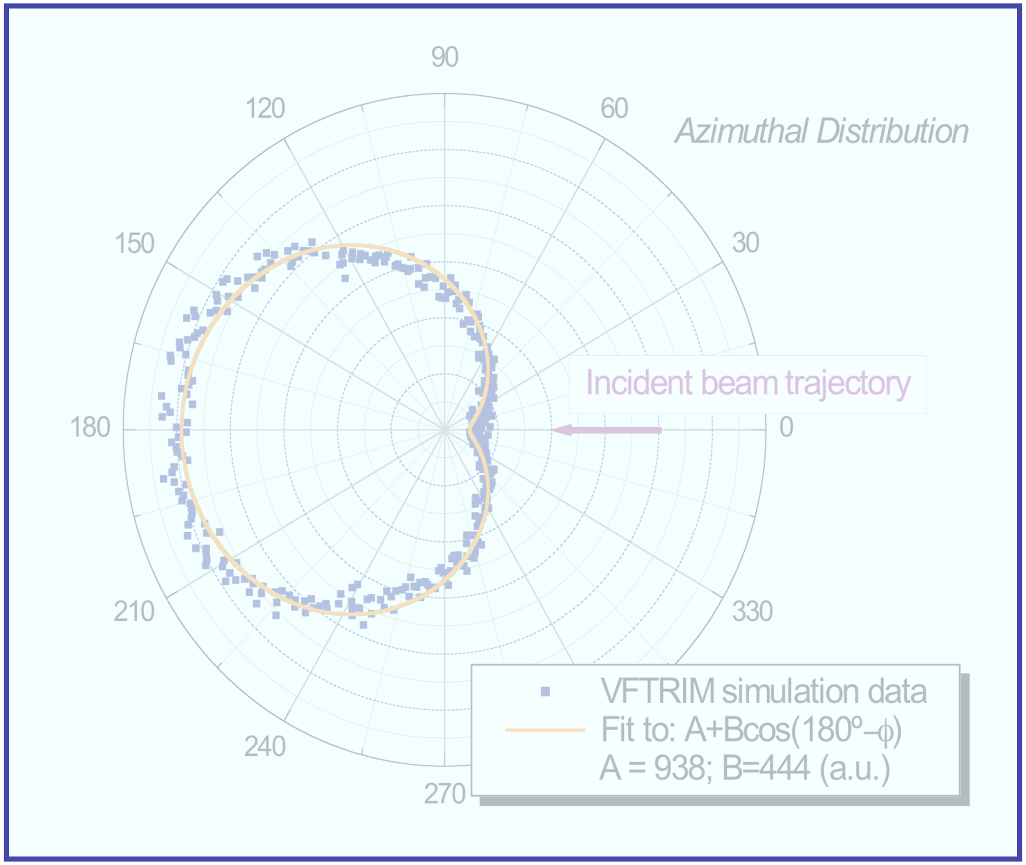


1000 eV $Sn^+ \rightarrow Sn$ at 45º incidence

(Polar angle)

- *A* and *n* are fit such that $A \cdot \cos^n\theta$ fits the VFTRIM polar “data”
- Previously assumed $\cos^1\theta$ polar distribution – This correction of *n* made little difference in the final result

Improved estimate of "geometric factor": 2



1000 eV $Sn^{+} \rightarrow Sn$
at 45° incidence

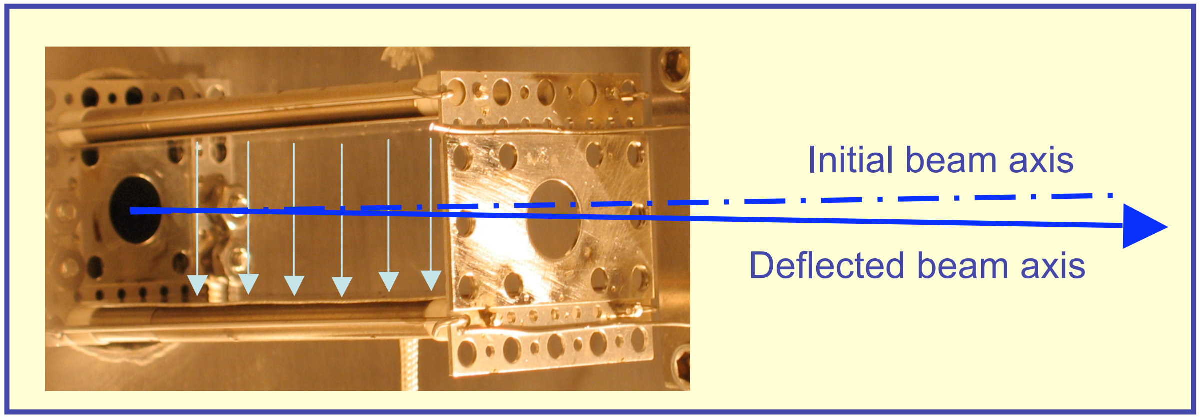
(Azimuthal angle)

- Previously assumed azimuthal isotropy
- Significant anisotropy due to oblique incidence
- Parameters *A* and *B* are varied using $A + B \cdot \cos(\varphi - \pi)$ to fit VFTRIM azimuthal distribution "data"

(NOTE: This function is just a guess that fits most data sets well and so doesn't necessarily have a physical interpretation)

Ion beam system modification
Neutral filter installation

- Installed horizontal deflection plates to make 3º bend to filter neutrals
  - Previously relied on Wien filter E-field to bend beam followed by 10 – 15 cm of 3.5-cm diameter tubing (along unbent beam axis)
  - Now, horizontal deflection for neutral filtering is performed after entering the main chamber to minimize neutral component
  - Unfortunately, this has degraded beam performance (as expected)



Prior target temperature was limited

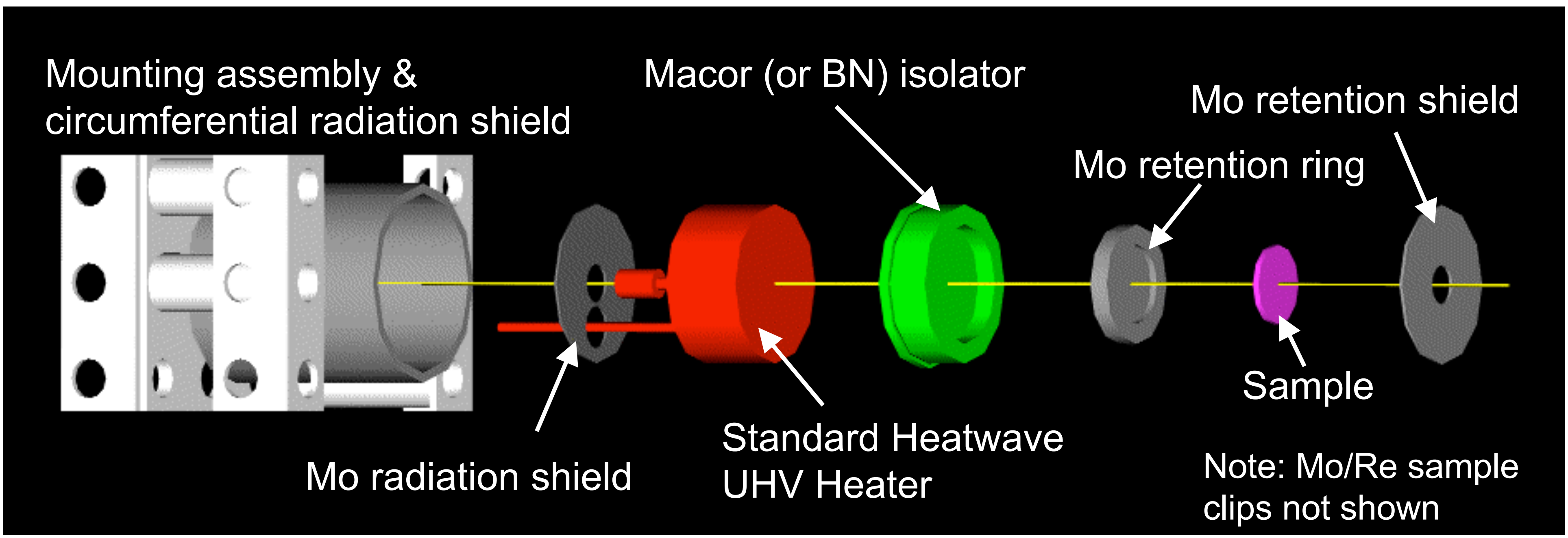
- Two factors…
  - Poor thermal considerations in target/heater holder design limited target to ~550ºC
  - Above ~420ºC, the QCM units would fail due to being close to the hot target without active cooling
- Recent hardware upgrades to allow high temperature measurement
  - Repaired QCM head for electrically-isolated water cooling
  - Installation of new target holder
  - Goal: Reach 1000ºC (Heater rated for 1200ºC)

Modification to QCM head:
Electrically-isolated water cooling

- Benefits:
  - Greatly improved crystal stability (better signal to noise ratio) at all temperatures
  - Able to exceed 870ºC without crystal failure with no apparent limit as of yet (heater power limit should be ~1100ºC)
  - Maintaining the same crystal temperature for all target temperatures
  - Use of a ceramic break and deionized water maintains electrical isolation
- Drawbacks:
  - Greatly reduced mobility of QCM head due to stiff "flexible" water lines
  - Marginally degraded base pressure due to use of Swagelok fittings (low 8's versus mid 9's on a good day)

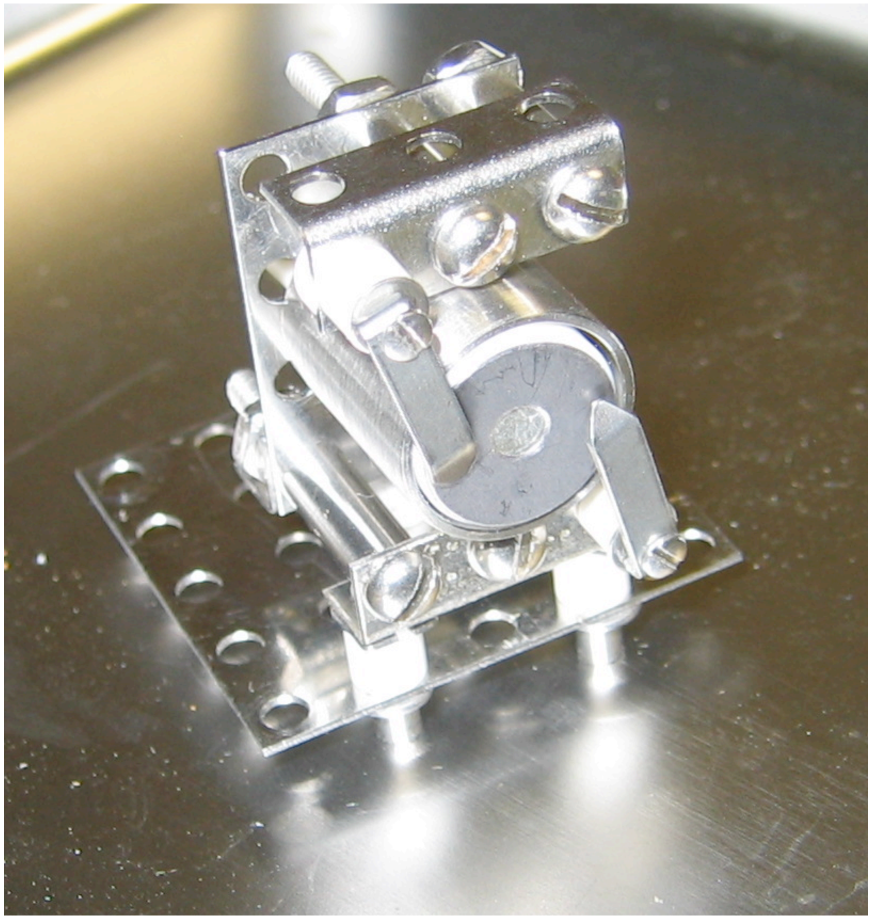
Heater & liquid sample holder redesign

- Thermal considerations
  - Minimized thermal contact between heater/target components and mounting hardware
  - Radiation shield around circumference (SS) and behind (Mo) heater to minimize radiative losses

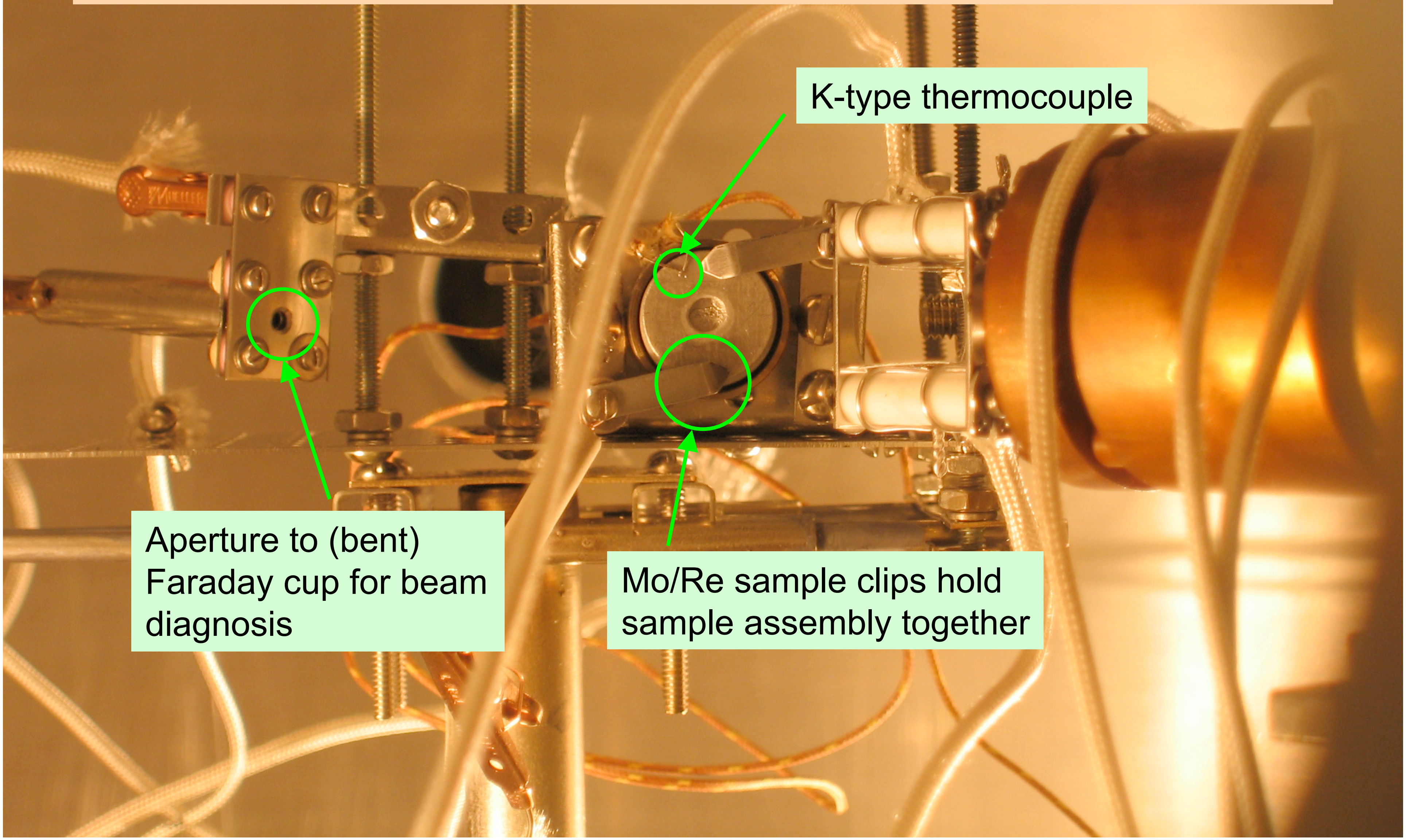


New sample holder construction

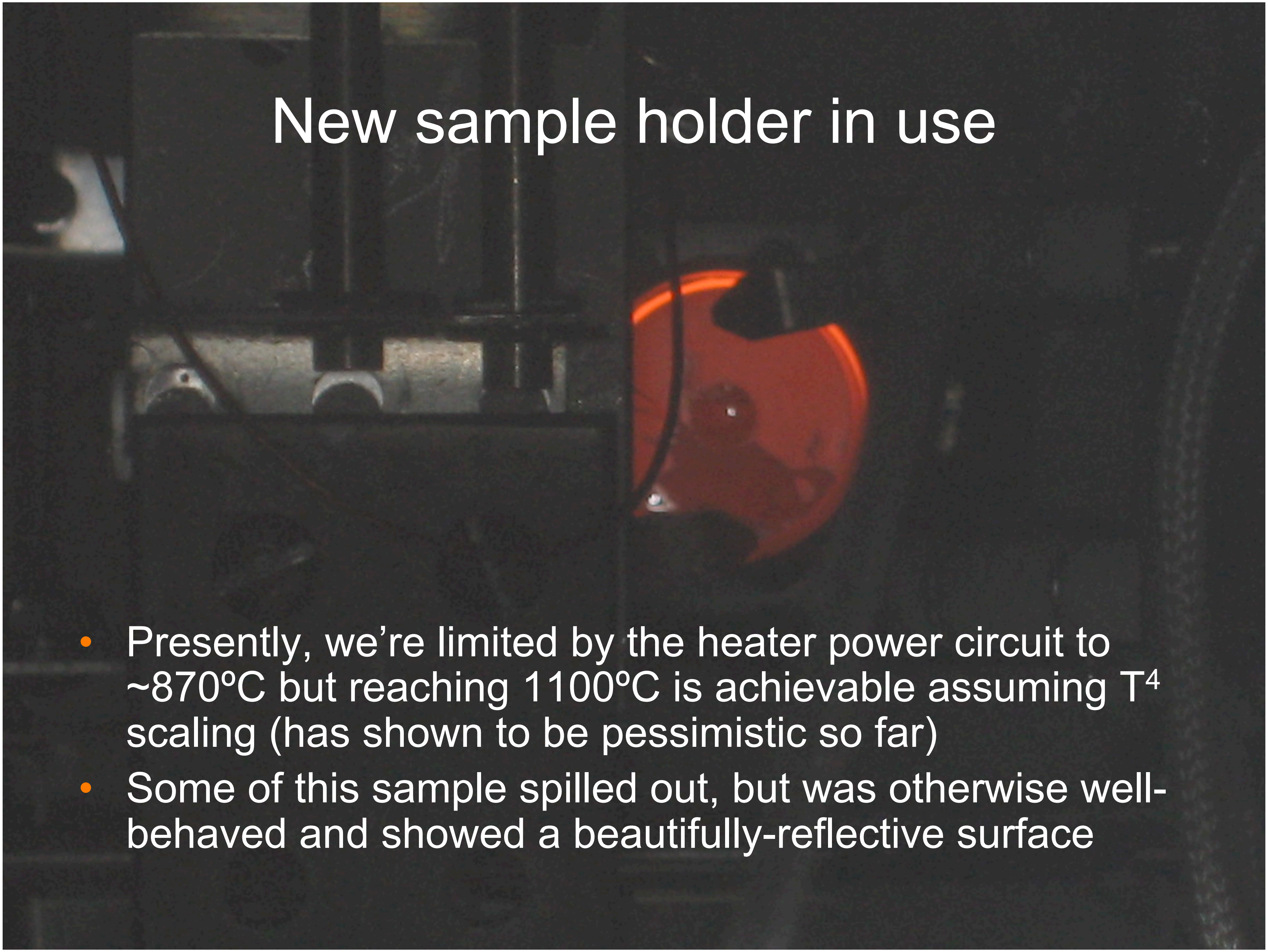
- Currently, only one assembly ‘hard’ mounted
- Goal: Several interchangeable sample assemblies
- Quick assembly replacement (through 6” CF port)
- Two samples mounted with others ready to minimize down-time
- Need:
  - Design & construction time
  - Feedthough
  - UHV-grade plugs



New sample holder in place



New sample holder in use



- Presently, we're limited by the heater power circuit to ~870ºC but reaching 1100ºC is achievable assuming T^4 scaling (has shown to be pessimistic so far)
- Some of this sample spilled out, but was otherwise well-behaved and showed a beautifully-reflective surface

Summary of modifications

- With improved data analysis techniques and an improved ion beam system, our data quality is improved
- To date, hardware limitations have kept our sample temperatures at or below 400ºC; since a Sn divertor's evaporation-limited temperature limit is estimated to be 1200ºC[1], higher temperature (and lower energy) measurements are needed
- IIAX hardware upgrade should allow sample temperature of at least 1100ºC

[1] Brooks, J.N., *Modeling of sputtering erosion/redeposition – status and implications for fusion design.* Fus. Eng. Des., **60** (2002) p515-526.

Future Work

- Near-term:
  - *Focus on light ion (He^+ & D^+) sputtering of liquid Sn at higher temperatures – up to 1000ºC*
  - *Return to heavy ion sputtering (Ne^+, Ar^+, and/or Sn^+)*
  - *Reduce ion energies used (ideally to 100-200 eV with use of decelerator)*
- Longer term:
  - *Temp. dep sputtering of liquid Sn & Ga*
  - *Model apparent mass-dependence of temperature-enhanced sputtering*
  - *Li^+ or Sn^+ sputtering of Mo & LM-coated Mo*
  - *Measurement of the ionized fraction of sputtered material of PFC*
  - *Mixed **solid** material sputtering relevant to ITER (W, Be, C, etc.)*

Acknowledgements

- For helpful and productive discussions…
  - Jeff Brooks & Jean-Paul Allain (ANL)
  - Bob Bastasz & Josh Whaley (SNL)
  - PFC community in general

- Undergraduate research assistants
  - Dan Rokusek (graduating, off to MIT)
  - Carolyn Tomchik (graduating, another group?)
  - Rachael Jabusch

- PMI Group technician: Matt (Hobie) Hendricks (leaving us soon?)

- DOE contract

Status of ELM Simulating Plasma Gun

T.K. Gray, B.C. Masters, R. Stubbers[1],
D.N. Ruzic

Plasma Material Interaction Group
University of Illinois, Urbana-Champaign

[1]Starfire Industries, LLC

Plasma-Facing Components Meeting, May 9-11, 2005, Princeton, NJ

Outline

- Overview of current ESP-gun machine
  - Pulse forming network, pre-ionization source, diagnostics
- Magnetic Field Topology
- Electrical Characteristics
- Plasma Parameters
- IR Measurements
- Summary

ILLINOIS

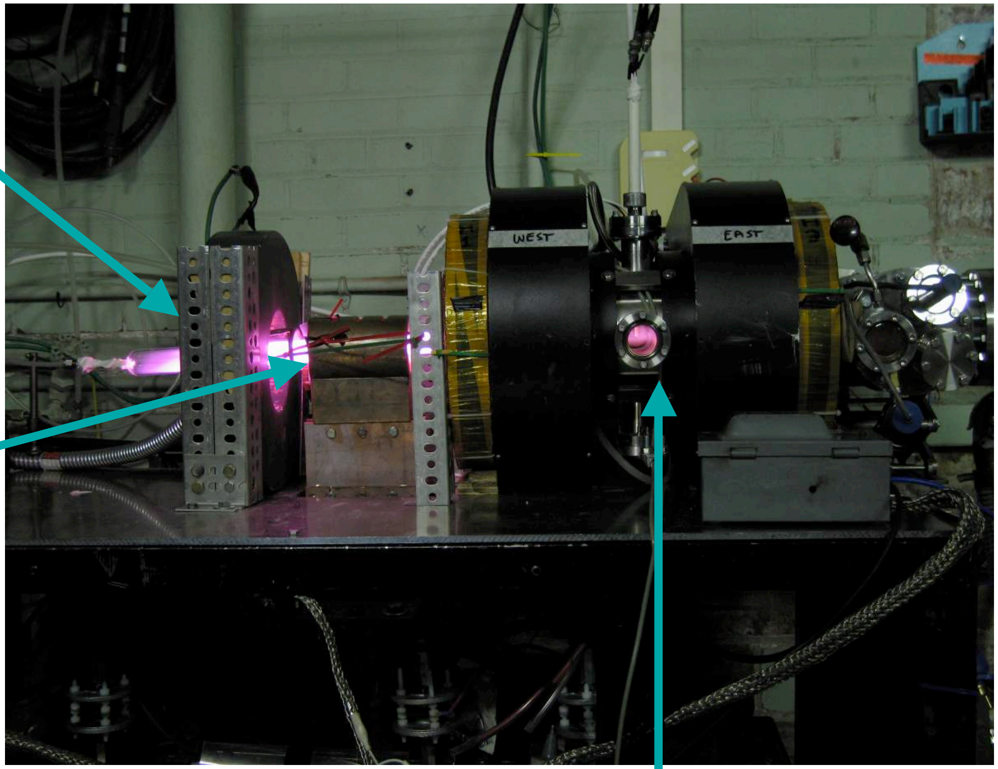
PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Introduction and Goals

- Type 1 Edge Localized Modes
  - 10 MW/m^2 on diverter surfaces
  - Create heat loading problem
  - Create debris and impurities from the diverter
- ESP-gun
  - Laboratory machine to reproduce ELM plasmas
  - Test heat loading and material properties under a simulated, laboratory ELM plasma

ESP-gun

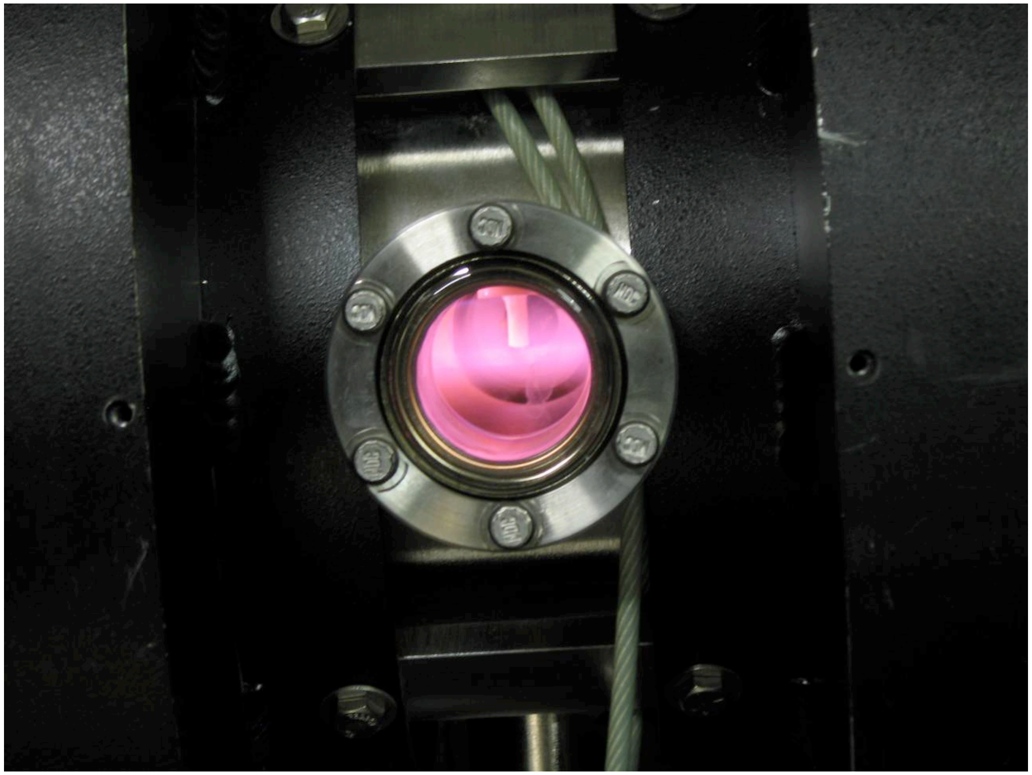
- RF pre-ionization source
- ECR magnets for down stream field
- Conical, theta coil
  - ~ 5º taper



Target Area

Diagnostics - presently

- High Voltage, high bandwidth probe
- Rogowski Coil
- Optical Emission Spectroscopy
- Electric Probes

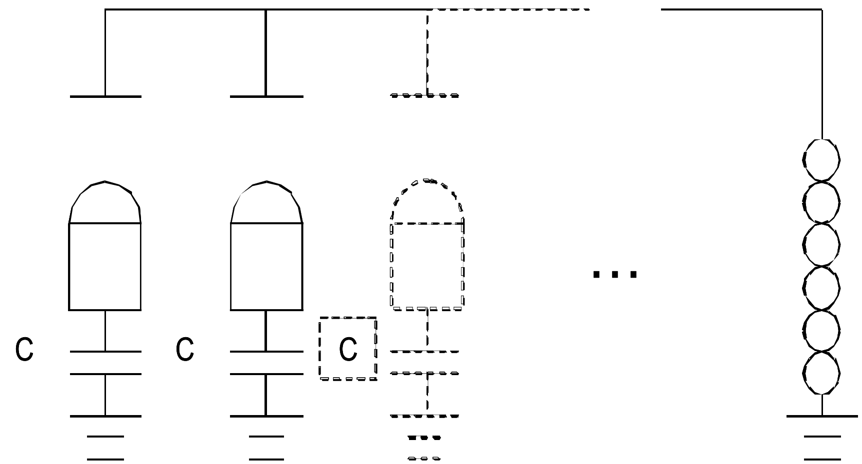


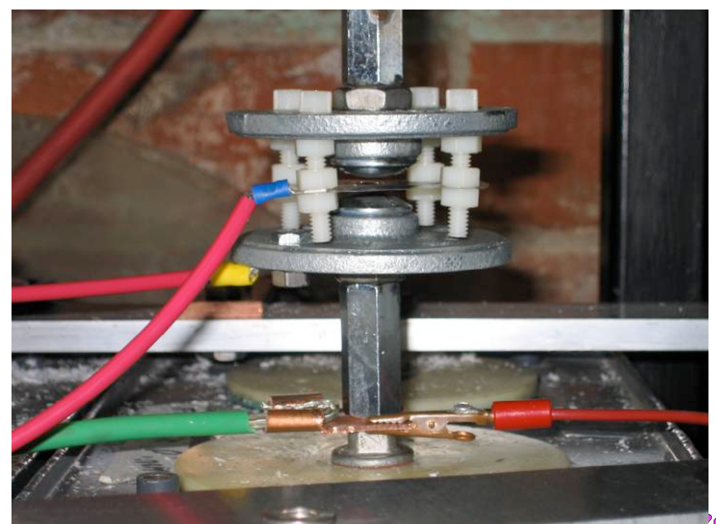
ILLINOIS

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Pulse Forming Network

- 3 smaller PFN’s
  - 55 μF, 500 nF Capacitor
    - 6 kJ total energy storage capacity
  - Low inductance transmission lines
  - ~ 100 kHz frequency
- Triggered Spark Gaps
- Each PFN is independently triggered

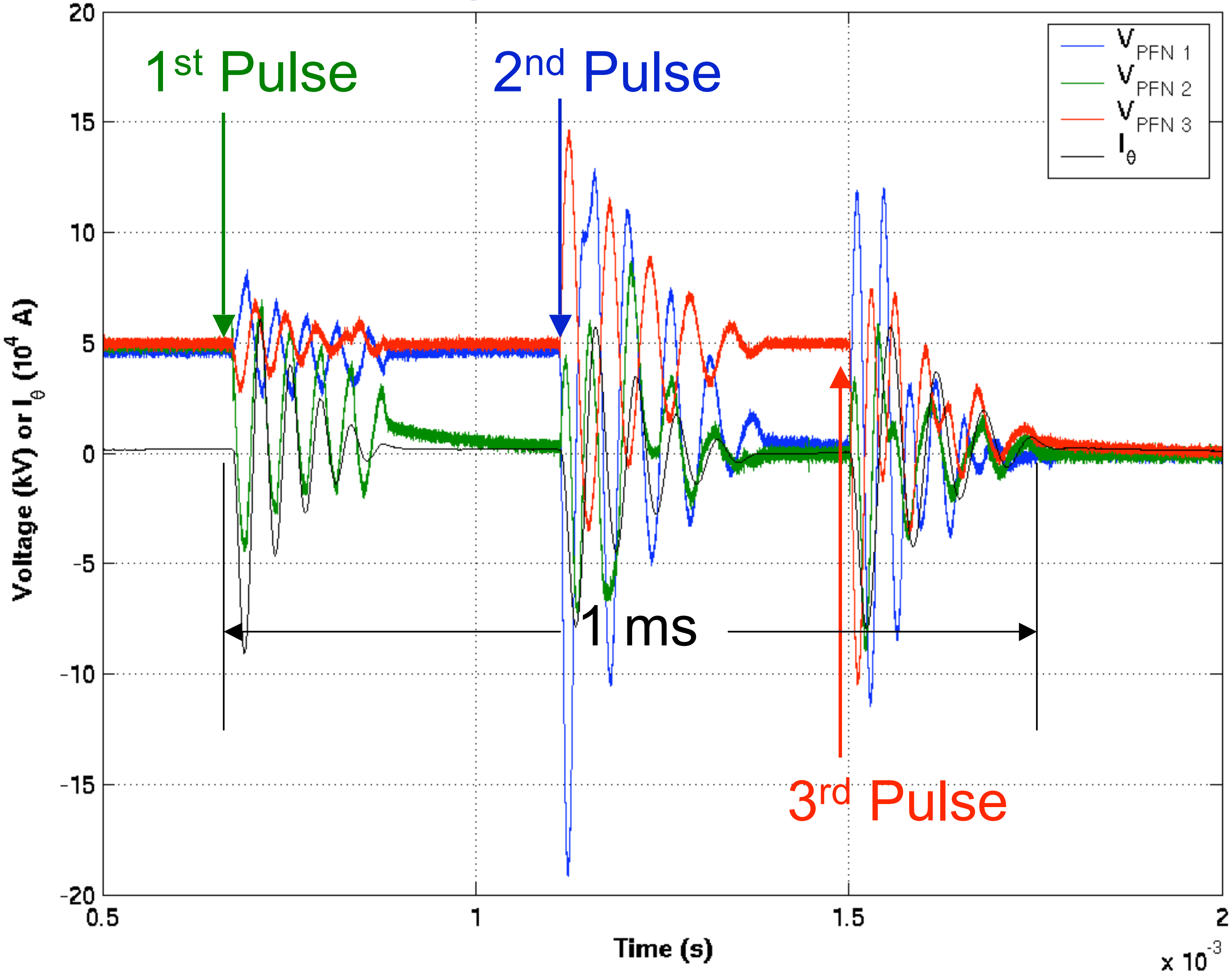




ILLINOIS

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Voltage and Current



PFN Results and Improvements

- 10 - 50 kA peak coil currents
- 250 μs total pulse length per PFN
- Rise time, $\lambda/4 \sim 13 - 16\ \mu$s

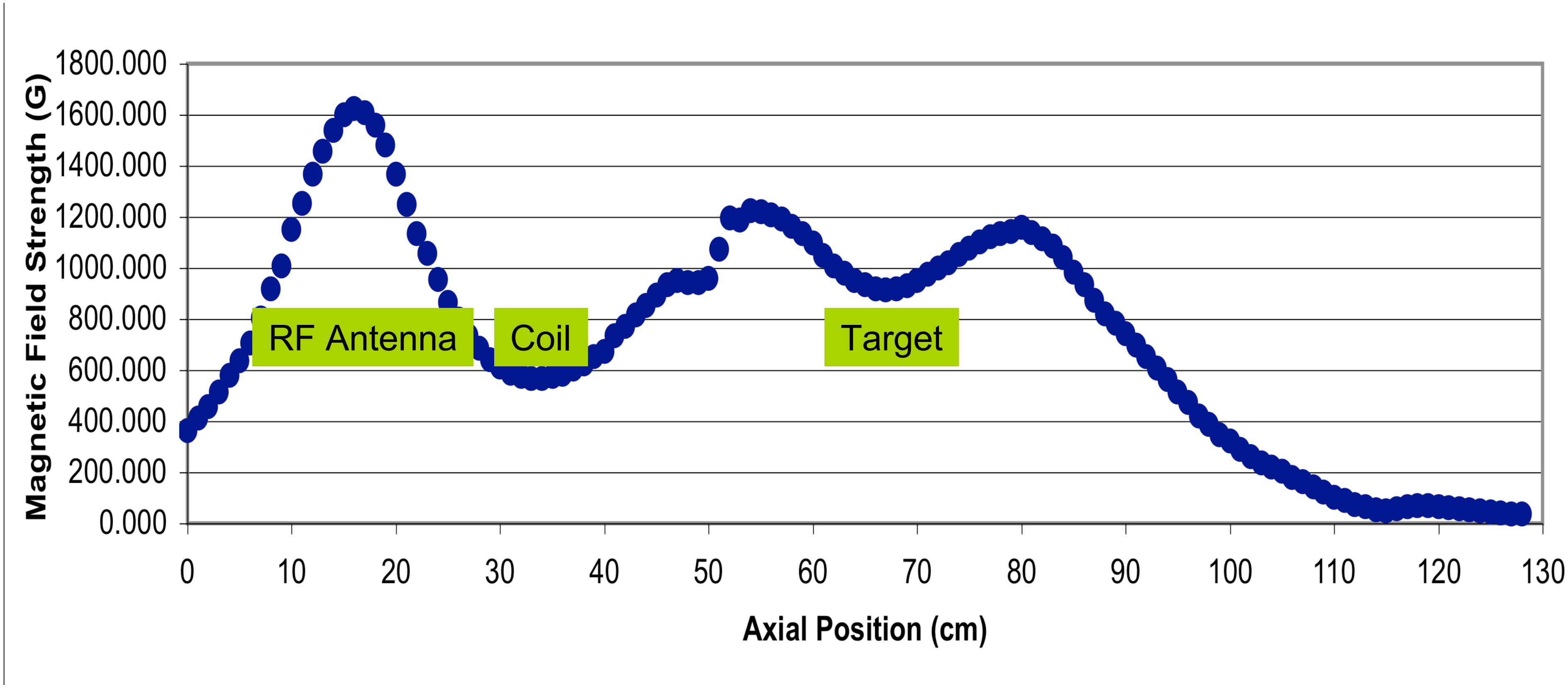
- L_{PFN} = 500 nH (cap inductance)
  - $\lambda/4$ is limited by caps!!!

ILLINOIS

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Magnet Field Topology

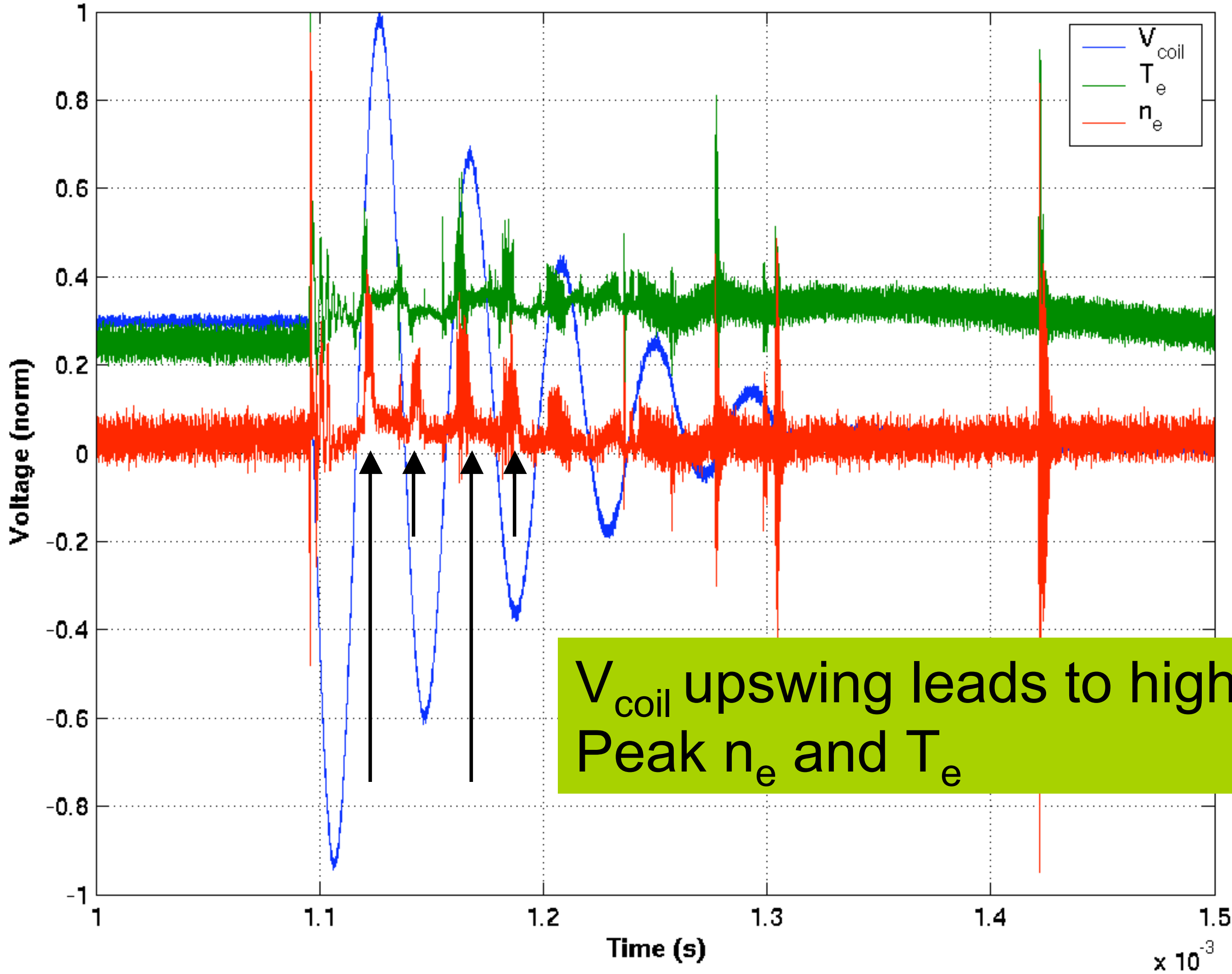
~ 990 G on target



ILLINOIS

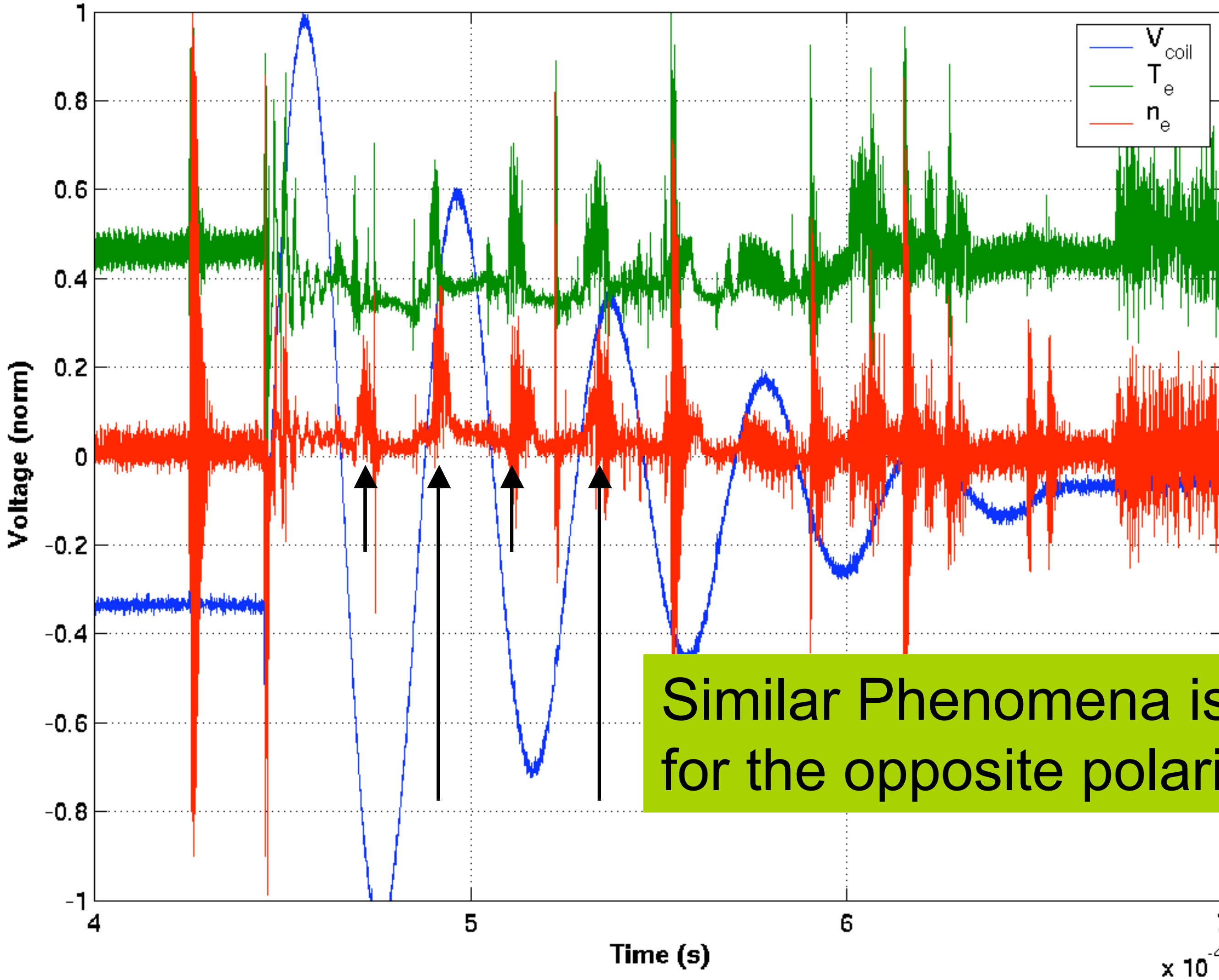
PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Typical TLP Trace



V_{coil} upswing leads to higher Peak n_e and T_e

Negative Charge



Similar Phenomena is seen for the opposite polarity

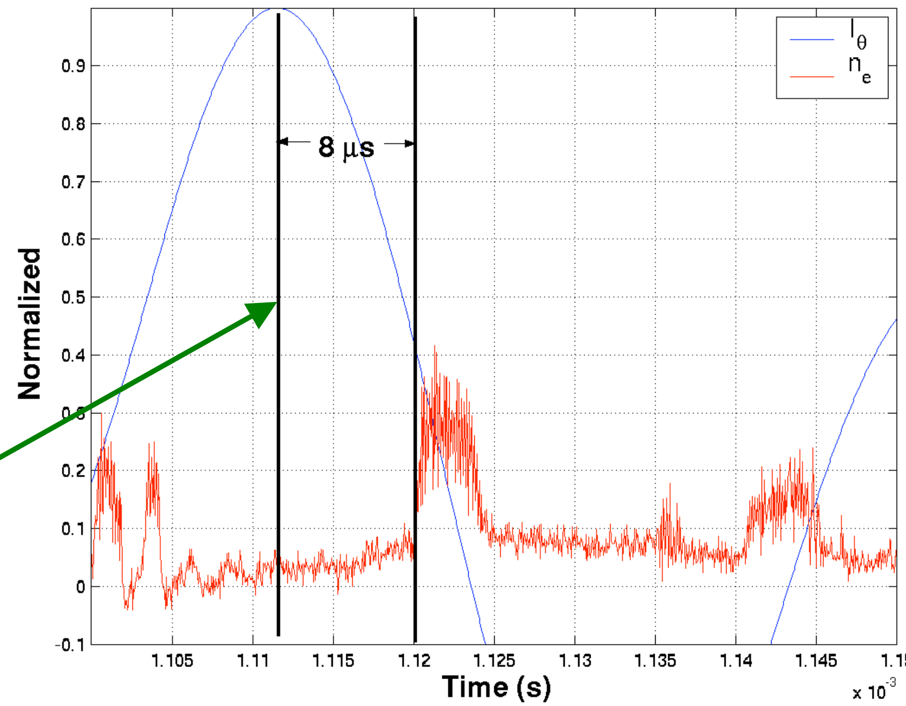
Plasma Behavior

- Upswing of the voltage
  - B_{coil} aligned with B_{ext}
- Downswing of the voltage
  - B_{coil} reversed with respect to B_{ext}
- Field Reversed Configuration (FRC) ?

Flow Velocity

- Estimate v from time of arrival of n_e
  $\langle x \rangle = 36$ cm
  $\langle v \rangle = 4.5(10)^4$ m/s
- $\langle v \rangle \sim v_{th}$

I_{max}, V=0



Summary

- Pulse Forming Network
  - 50 kA, 250 μs per PFN
  - Multiple (3) PFNs → pulse length ~ 1ms
- Peak Plasma Parameters (at 50 kA, 2kJ in)
  - $n_e \sim 1(10)^{18}$ /m^3
  - $T_e \sim 15 - 20$ eV
  - $\langle v \rangle = 4.5(10)^4$ m/s
- Possible FRC Formation

Acknowledgements

- ALPS/DOE Contract: DEFG02-99ER54515
- STTR - Starfire Industries, LCC
- PMI Group Members:
  - Mike Jaworski
  - Lab Technician, Matt Hendricks
  - Dan Schulz, Patrick Mangan, Joe Mestan

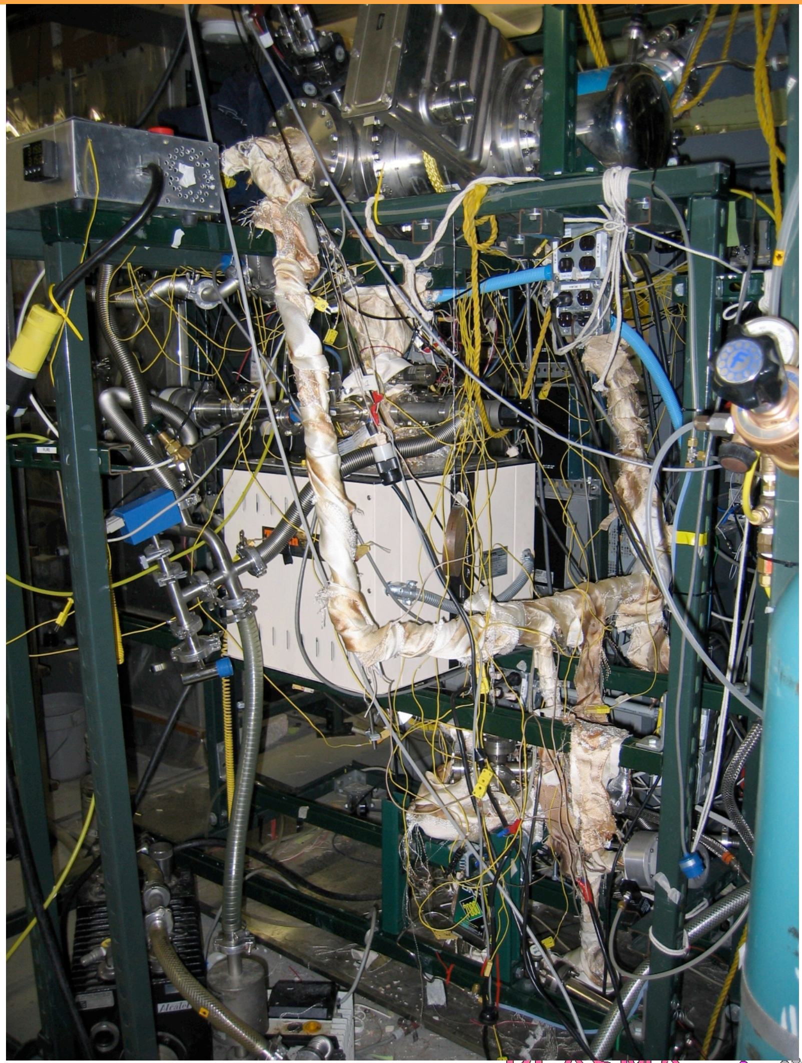
Re-examining Helium Retention Experiments and Redesign of FLIRE

P.W. Brenner, D.N. Ruzic, B.J. Schultz, R. Stubbers

Plasma Material Interaction Group
University of Illinois at Urbana-Champaign

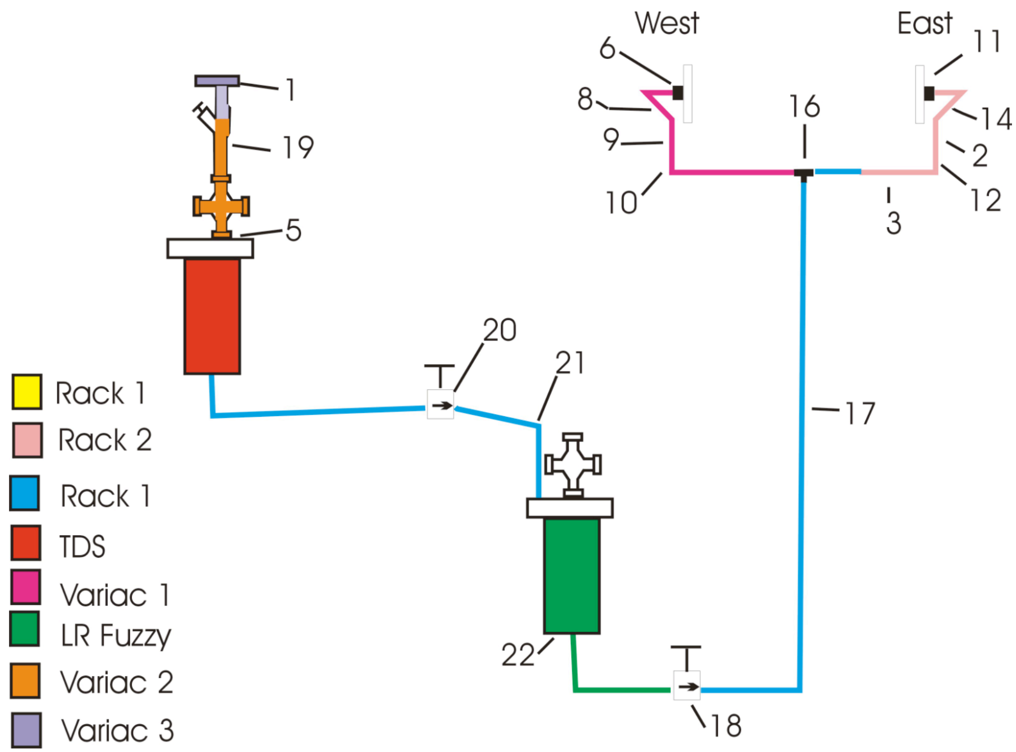
Overview

- Redesign of FLIRE
- Previous Results on He Retention
- Changes made to re-examine data
- Current results on He retention
- Future work on FLIRE



FLIRE has been redesigned

- Troubles in previous designs include cold spots and clogs
- New design focuses on reducing Li path length
- Remaining components include upper chamber, TDS, lower chamber, and Li transfer lines
- Viewports have been added to see flow from upper chamber to TDS
- All metal valve has been added between upper chamber and TDS
- Shutter has been added to protect ramp from ion beam



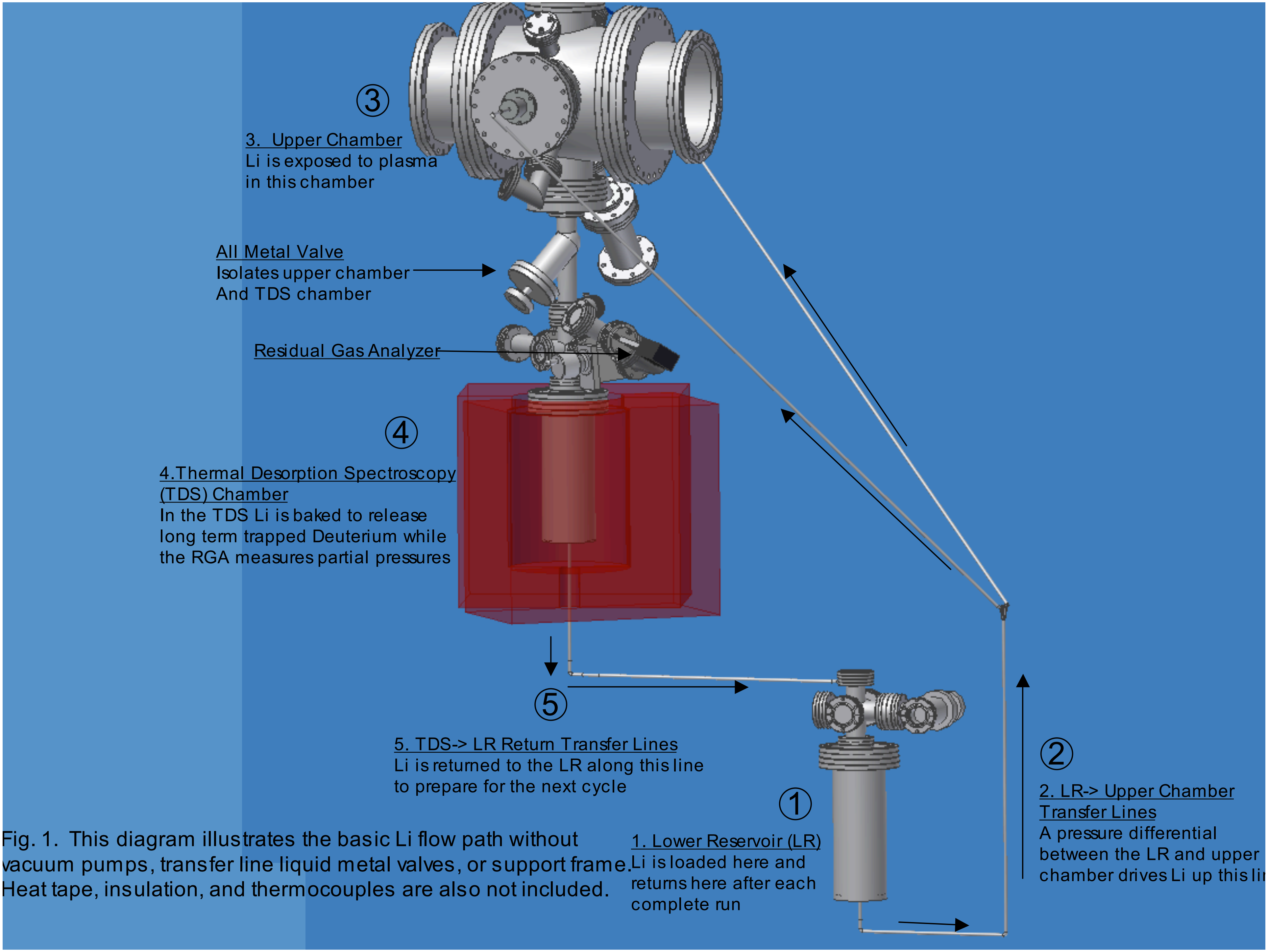
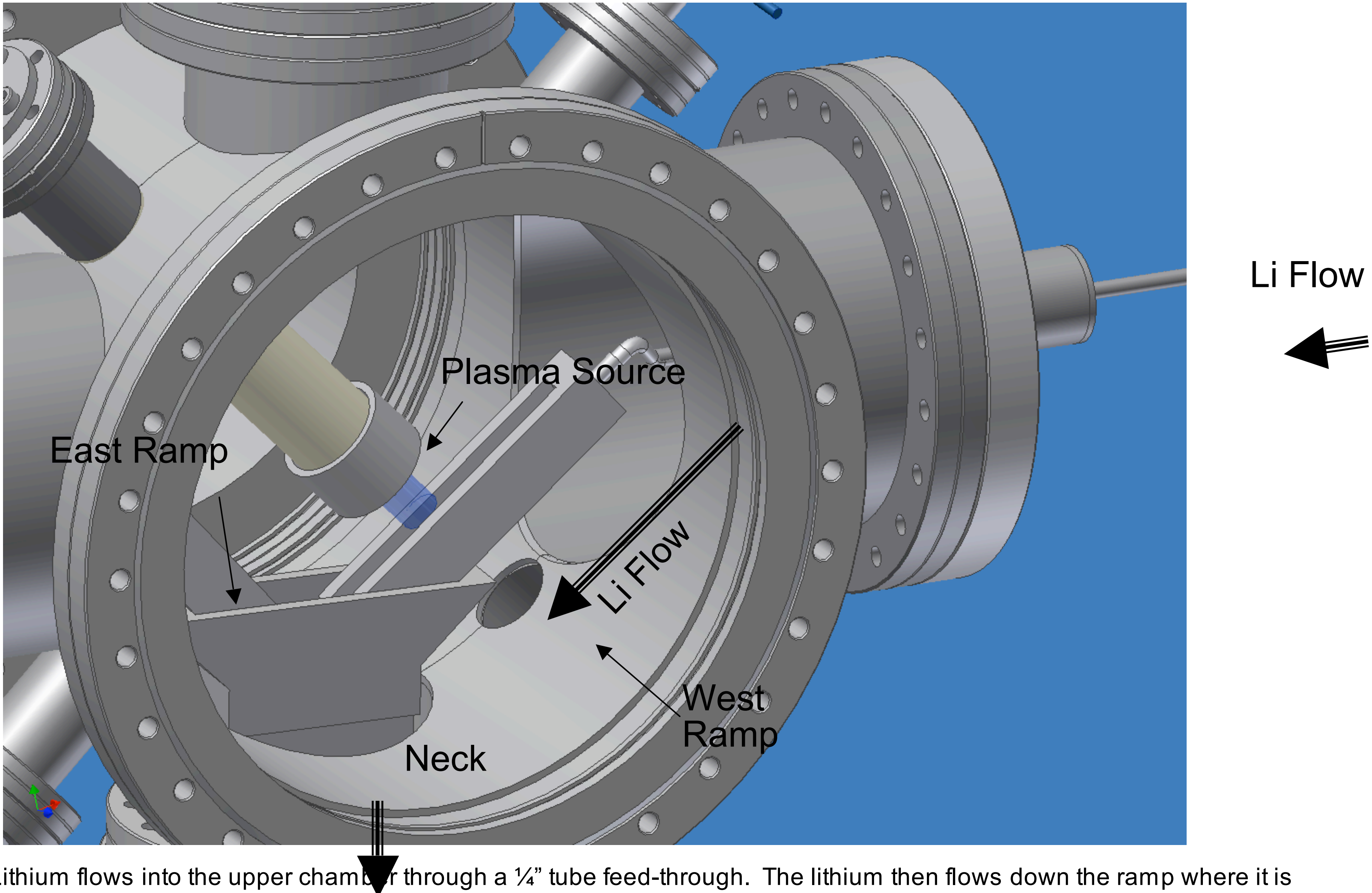
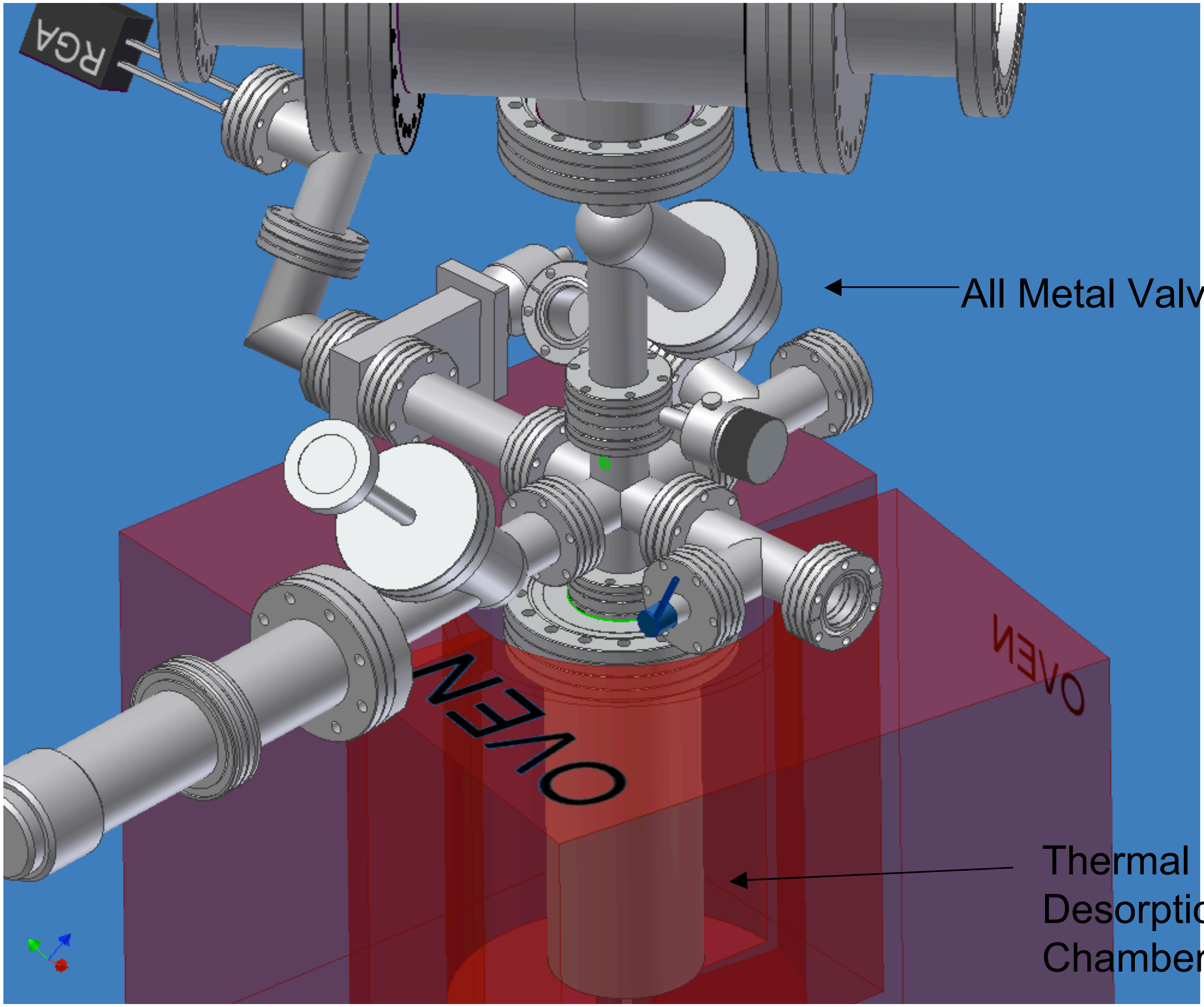


Fig. 1. This diagram illustrates the basic Li flow path without vacuum pumps, transfer line liquid metal valves, or support frame. Heat tape, insulation, and thermocouples are also not included.



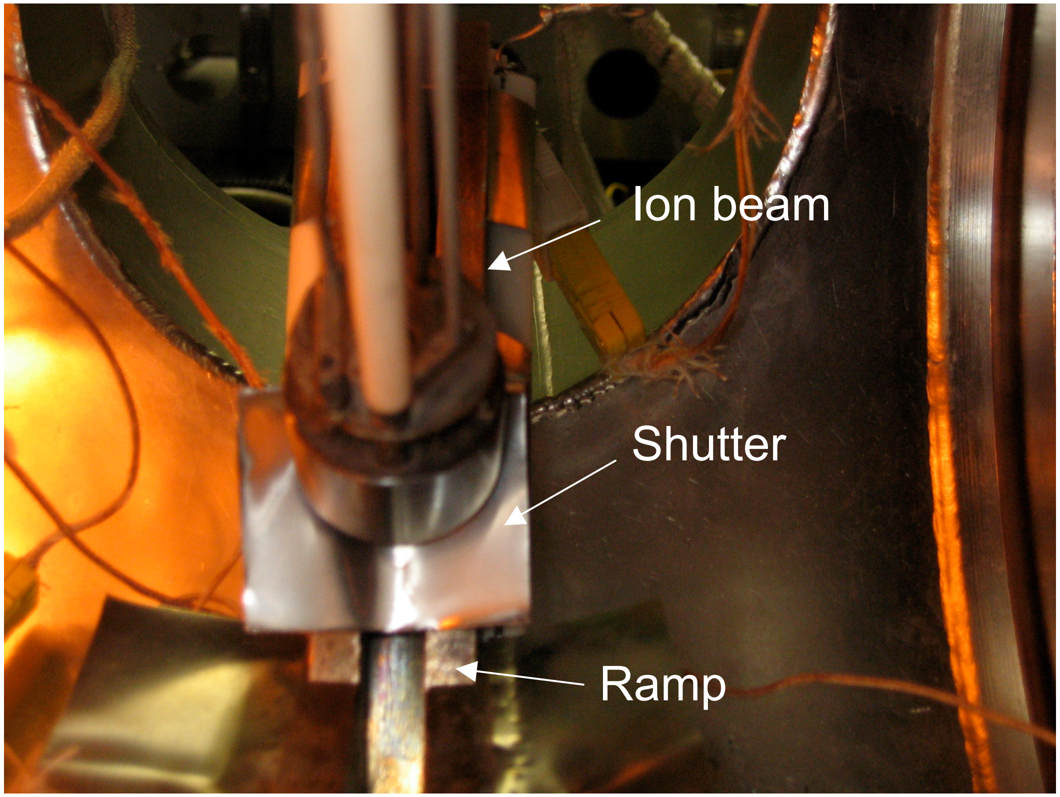
Lithium flows into the upper chamber through a ¼” tube feed-through. The lithium then flows down the ramp where it is exposed to the plasma. After exposure the west flow meets the east flow in the neck where they fold into each other, trapping any retained Deuterium until the lithium exits the neck into the Thermal Desorption Spectroscopy (TDS) chamber.



The thermal desorption chamber sits in an oven below the upper chamber. After exposure lithium can flow through the open valve straight into the desorption chamber for baking. While the Lithium bakes, The upper chamber is isolated by an all-metal valve having a nickel bonnet.

A shutter has been added to protect the ramp from the ion beam

- Previous experiments have not taken He implantation on steel ramp into consideration
- A shutter has been added to protect the ramp
- Shutter can be opened once Li flow starts and closed before flow ends



The focus of experiments has been to reconfirm He measurements

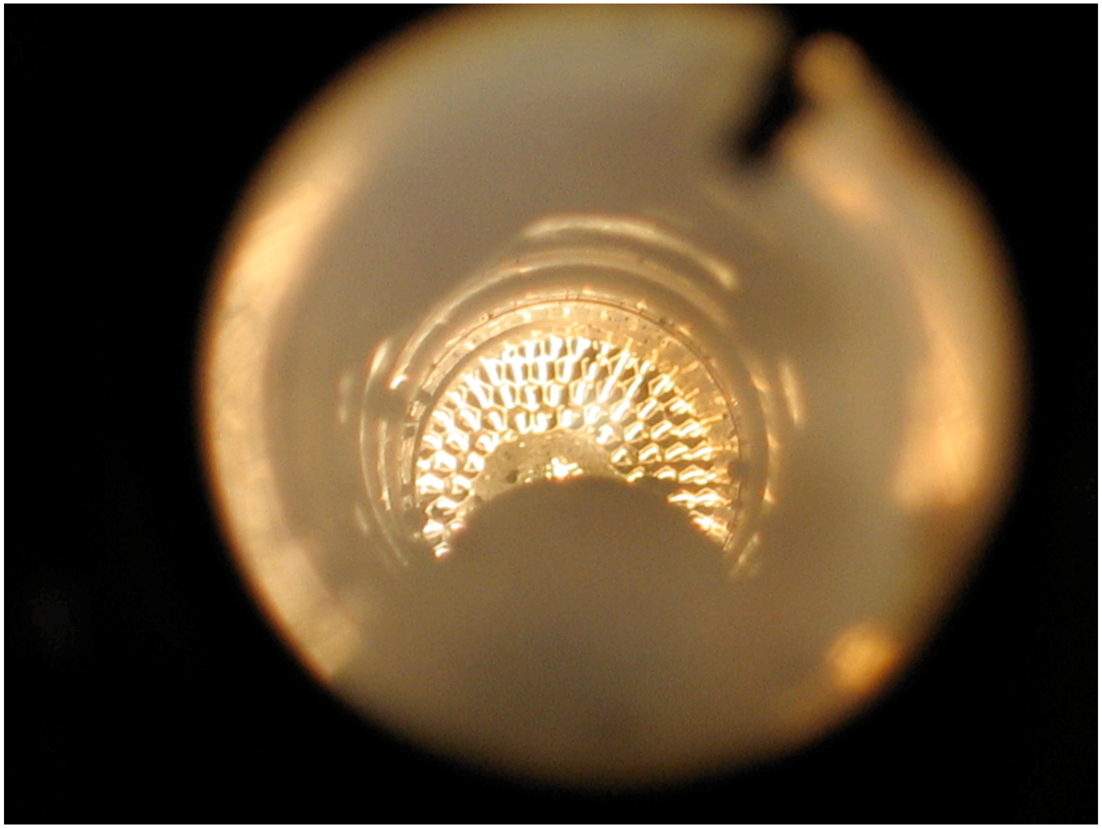
- Specific Tests Examined
  - Ion Gun Shutter (IGS) closed during flow
  - IGS only open during flow
  - IGS open before flow to inject D into ramp and closed as soon as flow begins

Previous Results – High Retention

- Could have been due to release of implanted D in bottom of SS ramp during the flow
- Could have been due to Li traveling as droplets or a film on the wall of the lower chamber – therefore releasing trapped He very quickly
- Could be due to as of yet unknown mechanism – which could also be present in a fusion device!

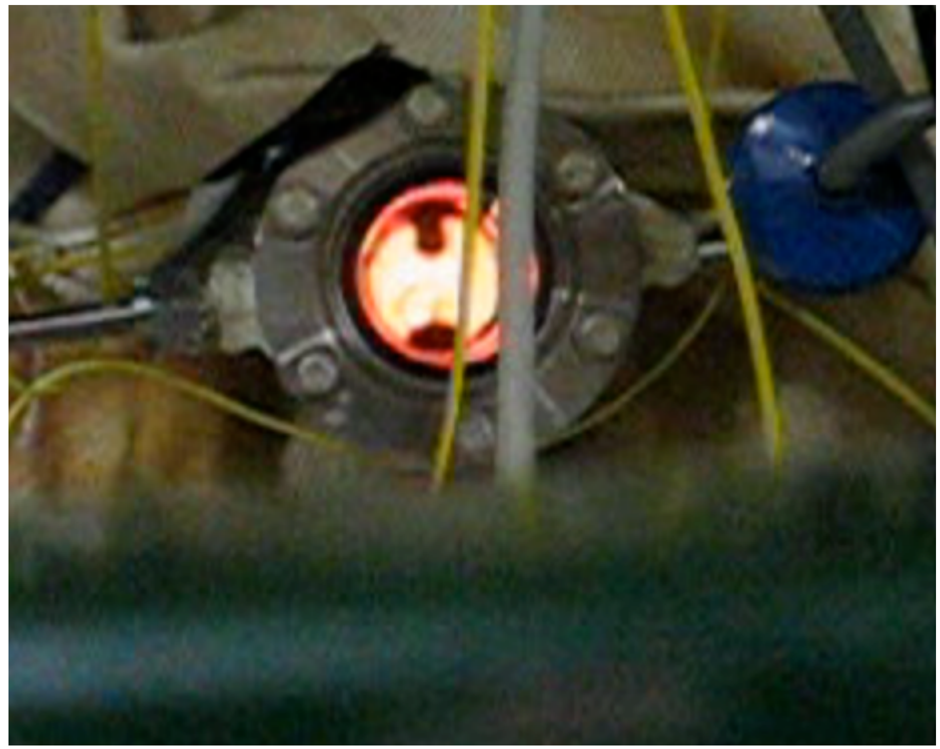
Flow between upper chamber and TDS can now be viewed

- Viewports allow access to view Li Flow and Li buildup in mid area
- Flow has been seen to be droplets initially and then flowing down the walls as Li built up in the chamber wetted the walls.

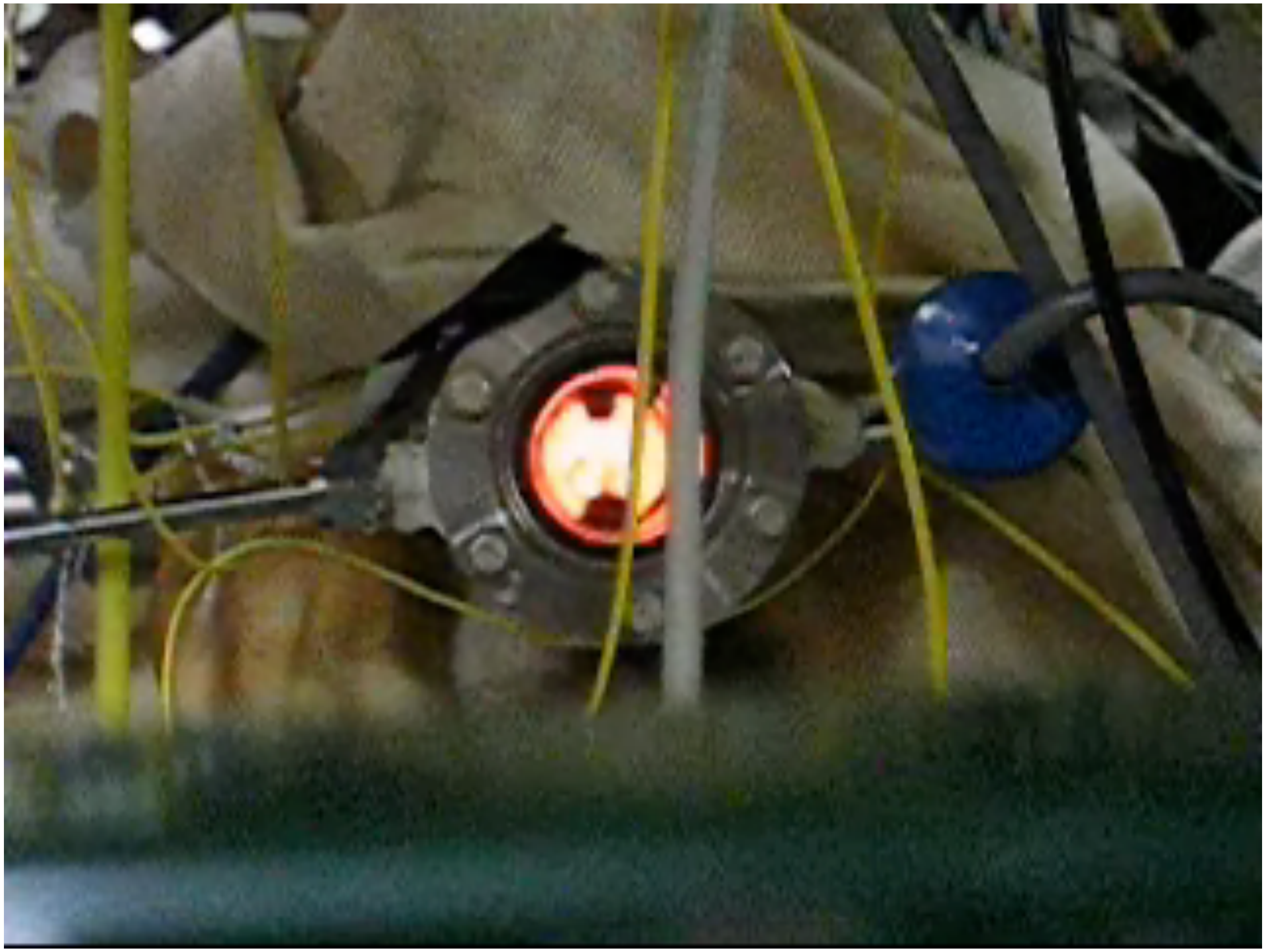


Droplet Flow

- Initial run with fresh Li and clean chamber showed droplet flow from upper chamber to TDS

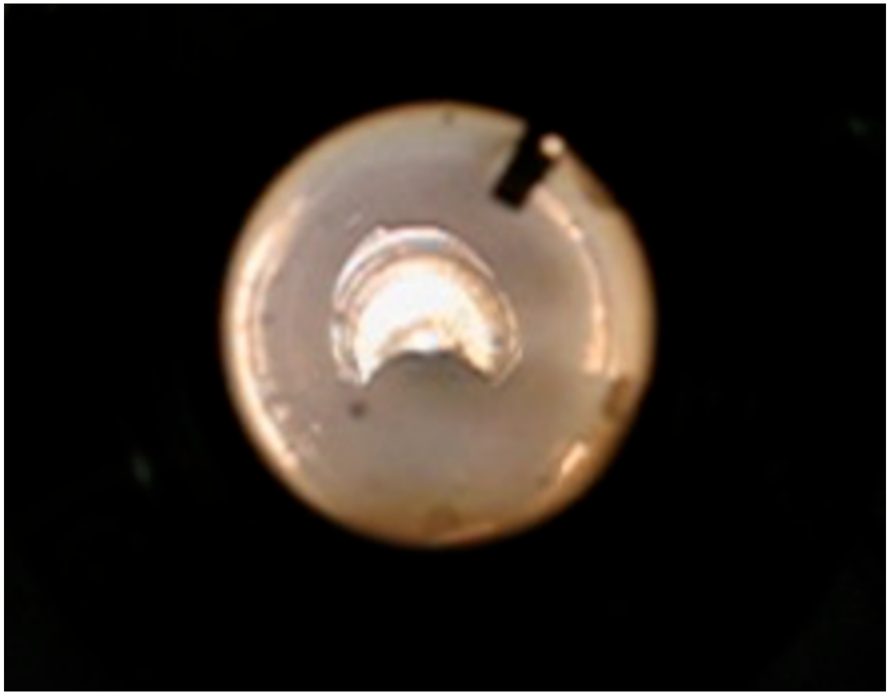


Droplet Flow Video

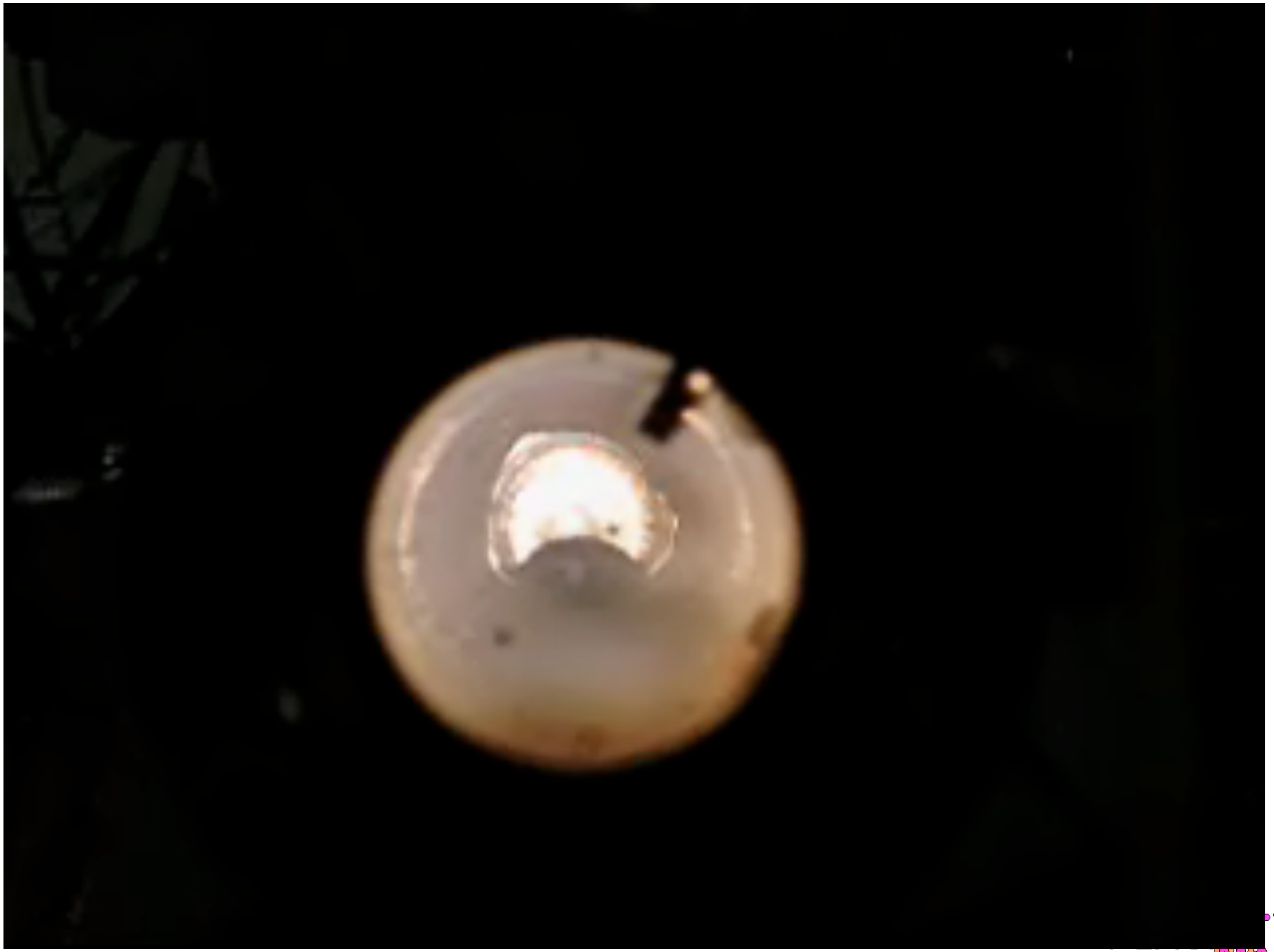


Wall Flow

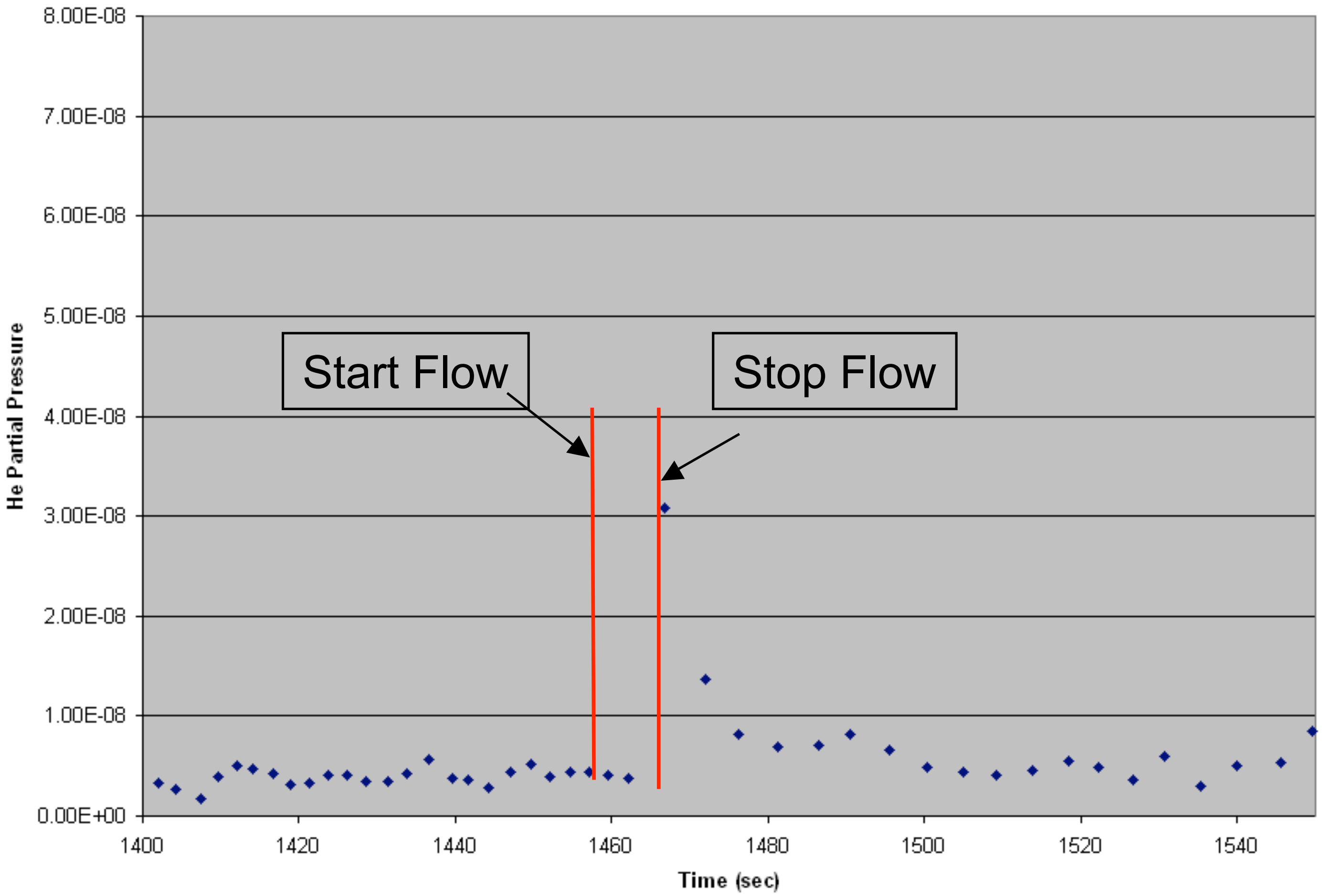
- After a Li fountain event which wetted all the walls, the flow was seen going down the walls as a film



Wall Flow Video



Shutter Closed (Ion Gun On)



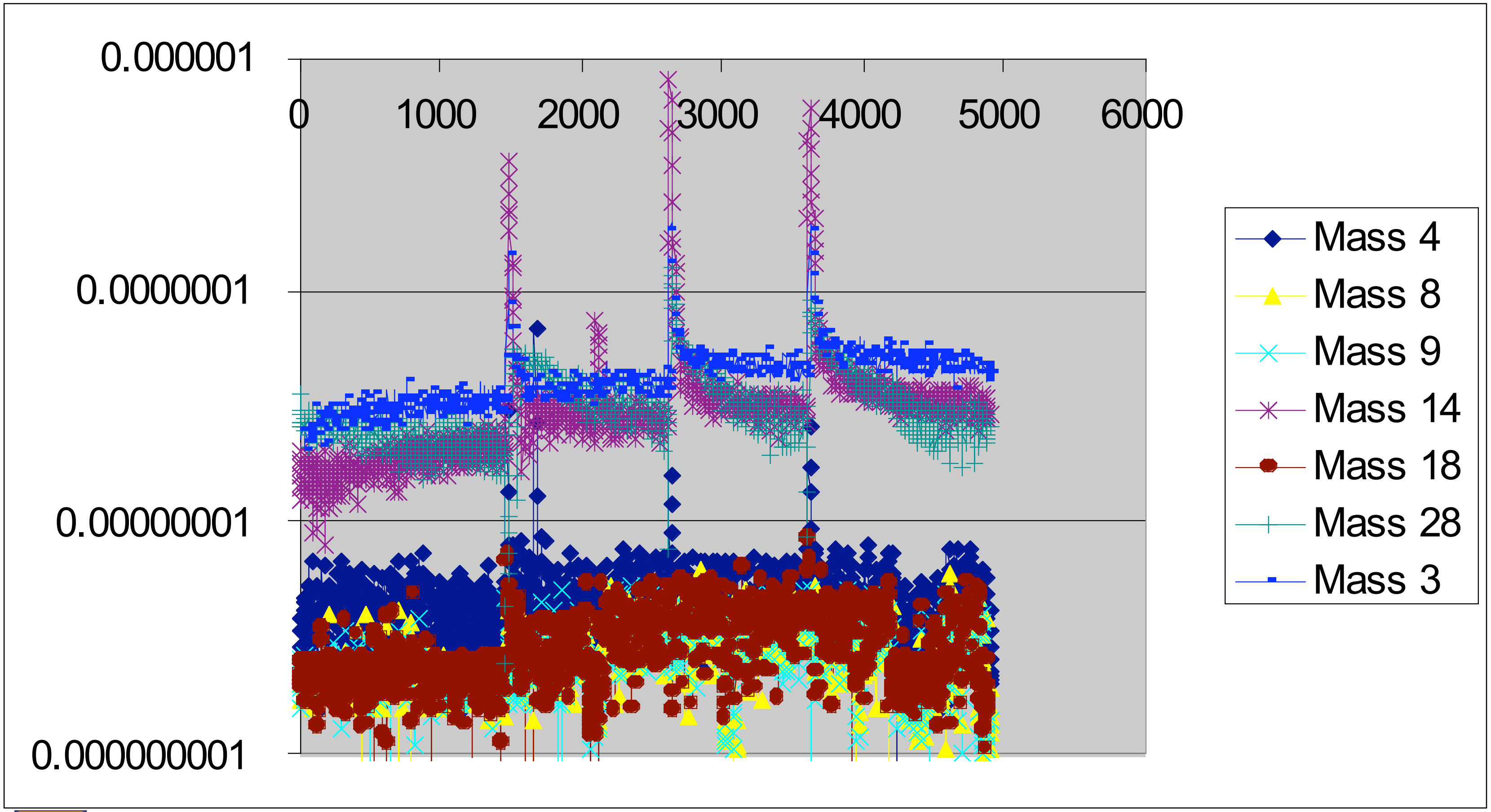
He signal seen when flow stops

Vacuum isolation momentarily breeched

ILLINOIS 1867

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Same signal seen in all ion species



ILLINOIS

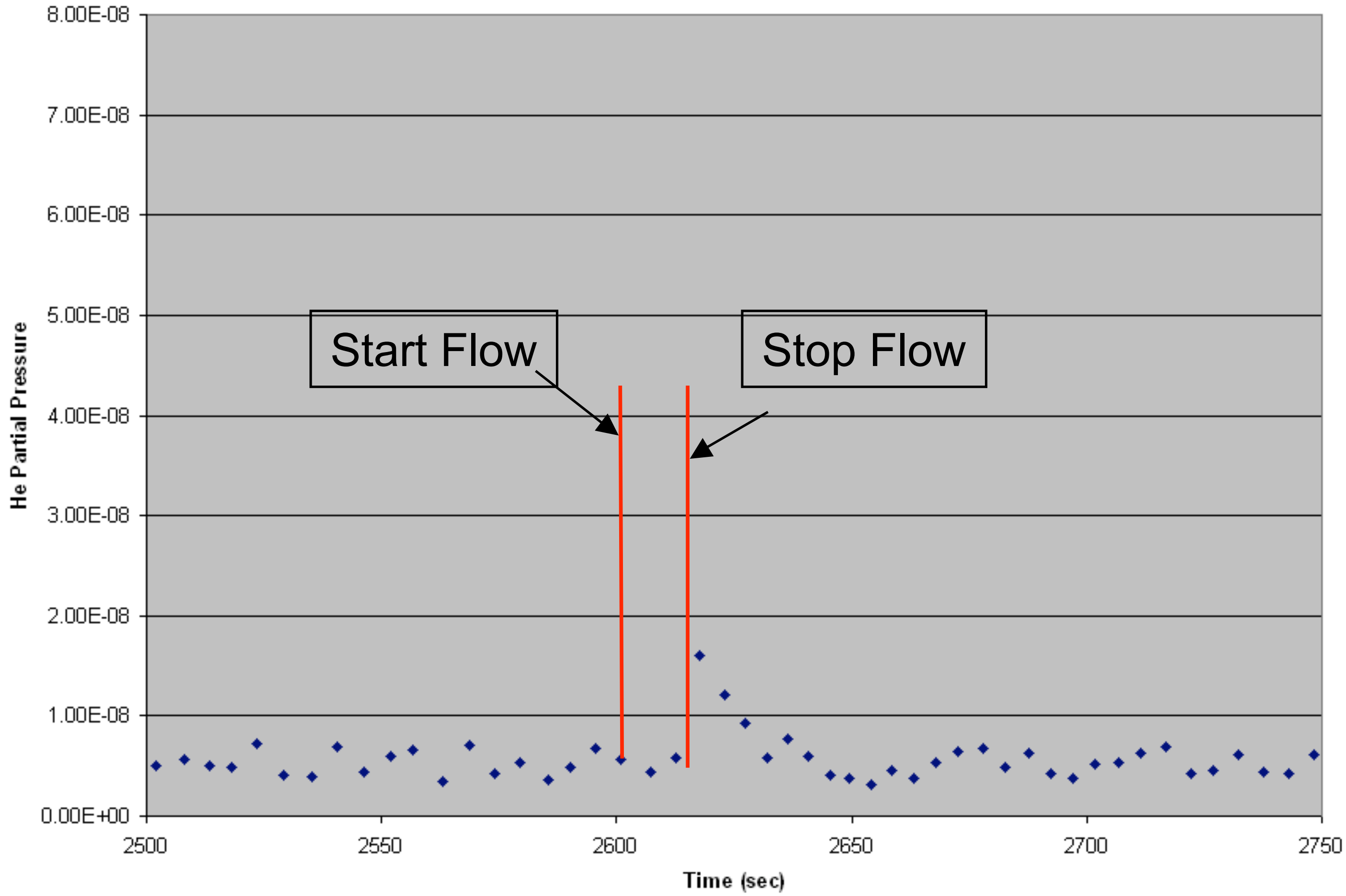
PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Why is this seen now ?

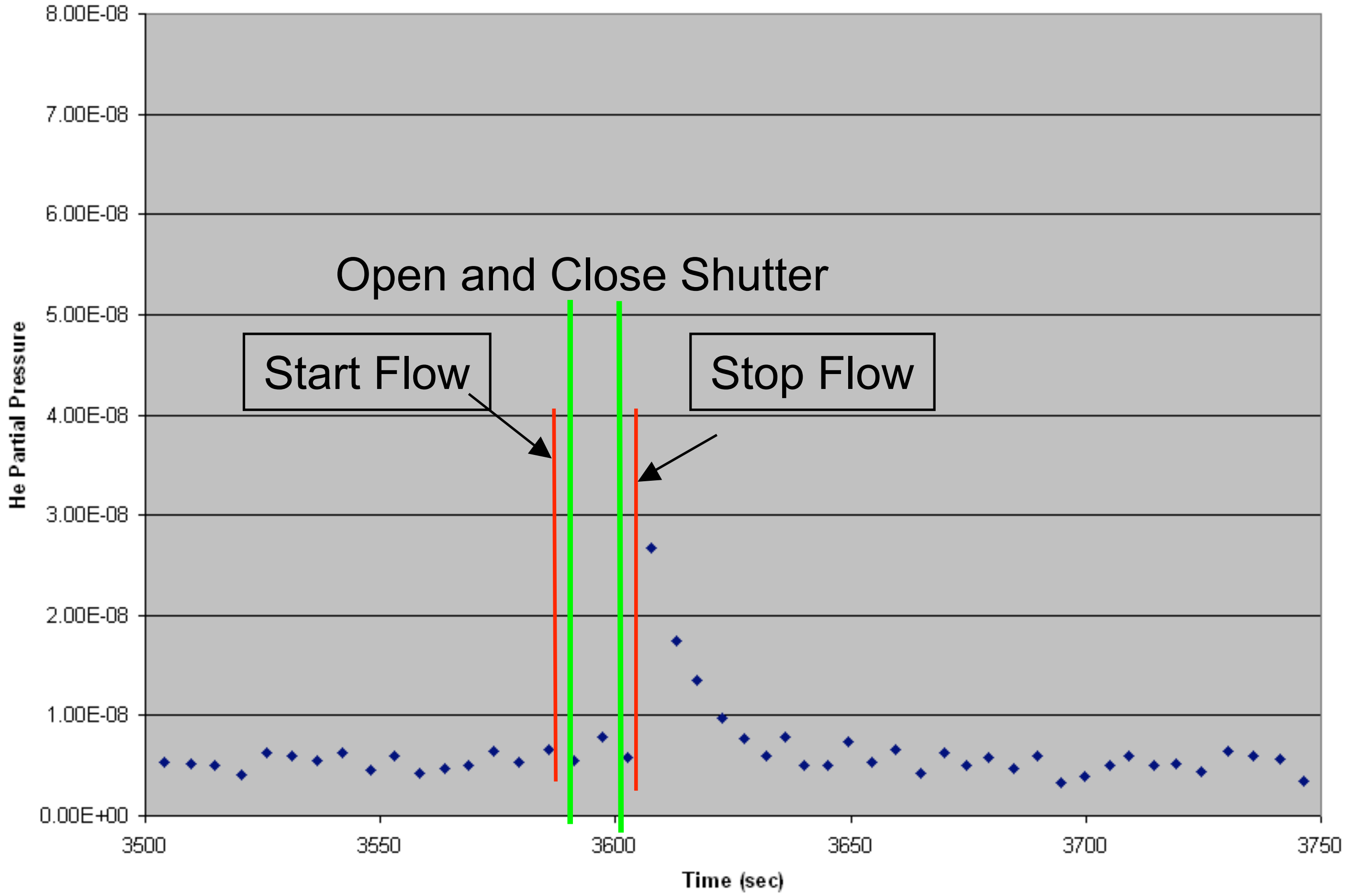
- Lower walls extremely wetted
- Ramp temperature is at 400 C due to heater failure on second ramp

- Under these conditions, momentum of flow likely opens a channel for a moment before meniscus forms re-establishing vacuum isolation
- However, this is at the end of the flow....

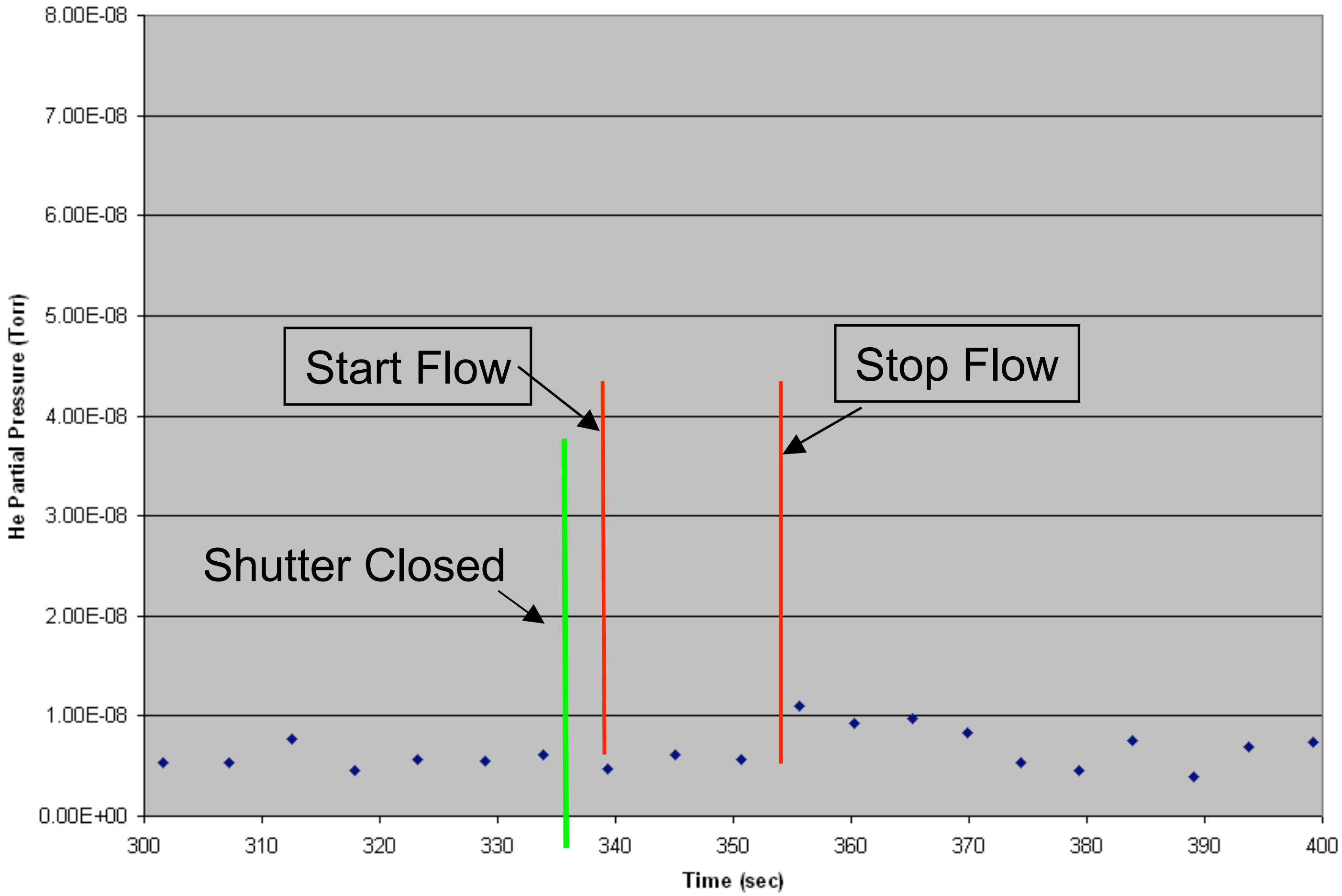
Same as last time: Ion gun on, Shutter closed whole time



Gun on, Shutter opened and closed during flow



Ion gun on ramp for five minutes, then shutter closed and flow started



Conclusions

- Runs to this date have been inconclusive
- Need to repeat with
  - Ramp temperature same as Li (230 C)
  - Higher time resolution on RGA
  - Longer Li flow times
  - Clean lower chamber to eliminate film flow and momentary chamber equilibration