SAND2015-10061C

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Impedance Dynamics in the Self-Magnetic Pinch (SMP) Diode on the RITS-6 Accelerator*

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56th Annual Meeting, APS Division of Plasma Physics

New Orleans, LA   October 27-31, 2014

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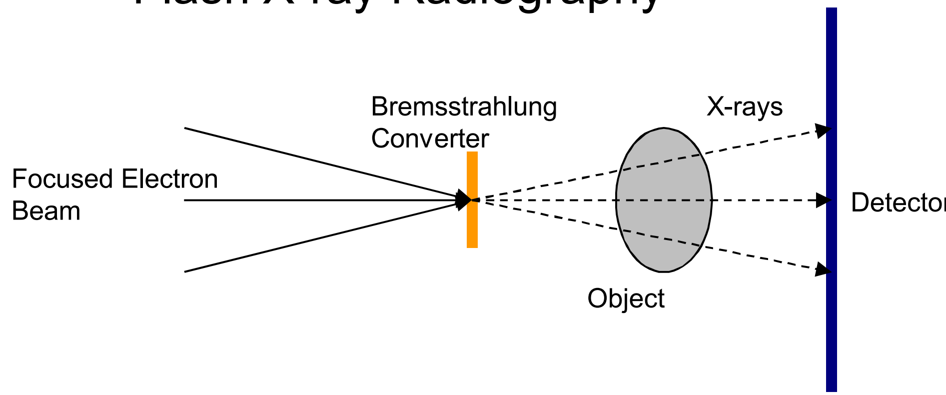
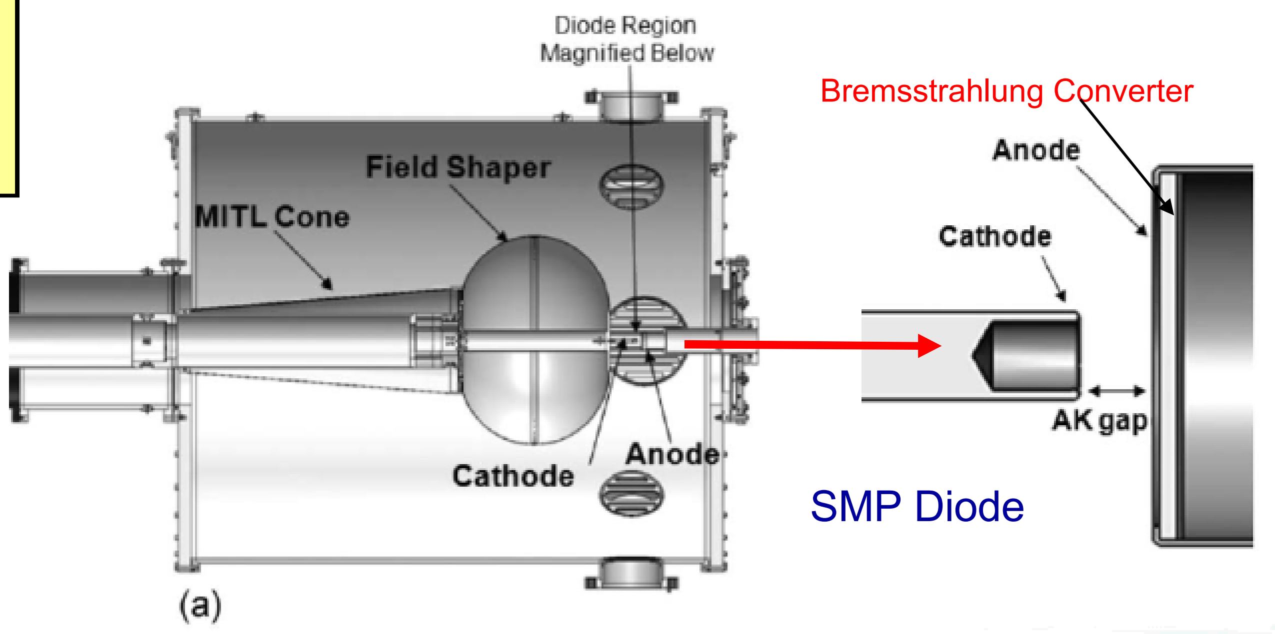
Schematic view: RITS front end

SMP Diode Parameters[2]

- 3.5-7+ MV
- 150 kA (~15% ions)
- 50 Ω Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- > 350 Rads @ 1 meter
- < 3 mm focal spot size

Flash X-ray Radiography

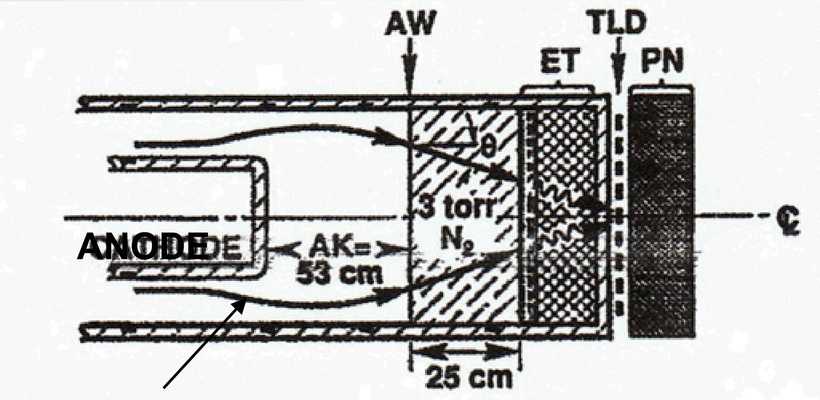




- **DOSE affected by:**
  - **Diode Voltage**
  - **Load Current**
  - **Voltage Duration (FWHM)**
  - **Electron angle on converter**

[1] K. Hahn, *et al*, *IEEE TRANSACTIONS ON PLASMA SCIENCE* **38 (10)**, OCTOBER 2010, pp. 2652-62.

The SMP diode has TWO sources of electron current plus ions

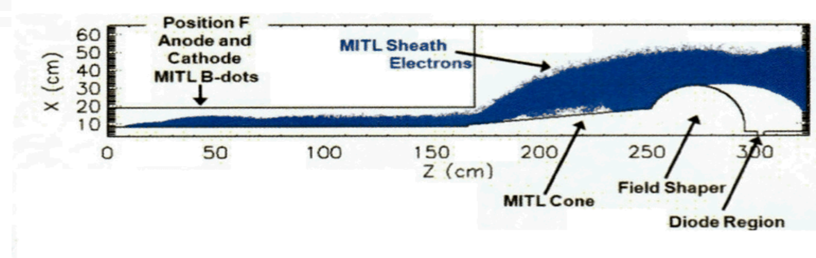


MITL electron flow

Bremsstrahlung diode on Hermes III[2]

- **Brems diode runs self-limited, large-area converter limits anode plasma formation**
- **SMP diode features electron pinch, ion formation to further reduce spot size, possible flow incorporation into load current**
- **SMP Issues:**
  - **Diode impedance varies with time, sends retrapping waveback into MITL**
  - **Ion source not well-defined**
  - **Need 'just-right' amount of ion current**

LSP simulation of MITL flow into SMP load



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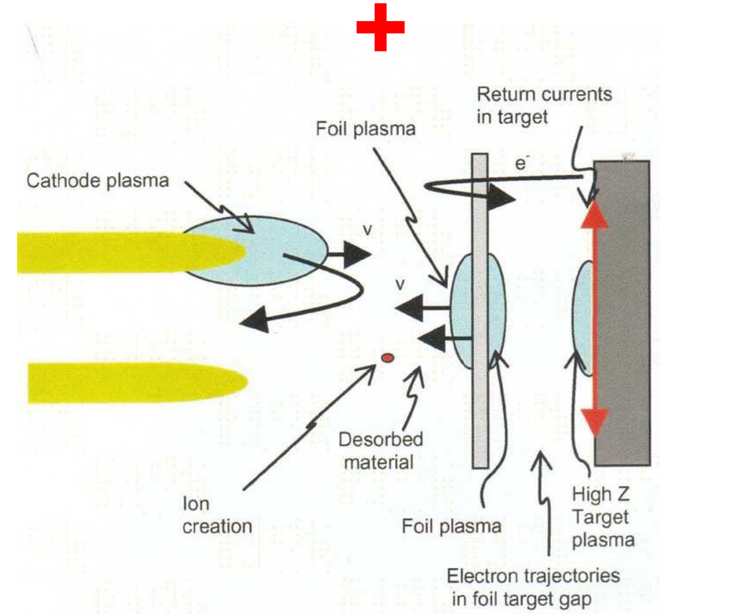

Fig. 2. Detailed schematic showing the SMP diode areas of interest.

SMP Diode[3]

[2] T. W. L. Sanford *et al*, J. Appl. Phys. **73 (4)** February 1993, pp.2004-14.

[3] P. N. Martin *et al*, *IEEE TRANSACTIONS ON PLASMA SCIENCE* **39 (10)**, OCTOBER 2011, pp.1943-48.

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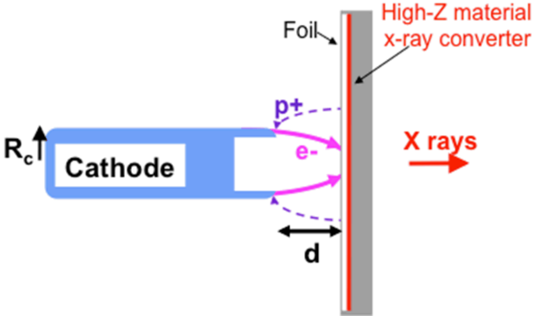
Performance goal: reduce Spot Size while maintaining Dose

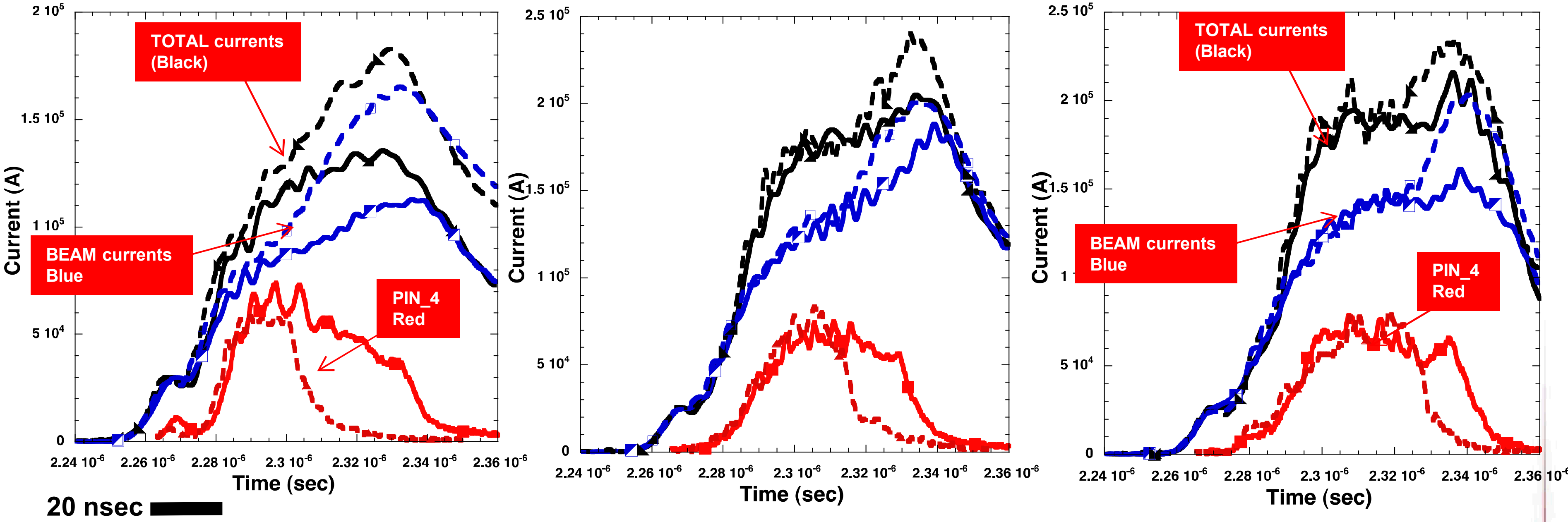
- Factors affecting Spot Size in the SMP diode
  - Output voltage: slight downward trend with rising voltage
    - 12.5 mm cathode – 12 mm A-K gap: 'Reference' for 8 MV operation, full FWHM, - need to reduce spot size
  - Cathode size: smaller cathode diameter → reduced spot size
  - A-K gap: smaller gap → smaller spot

- Downside to smaller cathode diameters and A-K gaps:
  - Lower impedance loads down accelerator, lowering Dose
  - Focusing optics appears to be more unstable e.g. spot size variability
  - E-beam pinch-in angle at converter increases, reducing dose-rate
  - Premature impedance (Z) collapse, which may be related to all the above

- Mitigation of these effects at smaller A-K gap a Work In Progress
  - Understanding Z-collapse is a Challenge
  - Materials changes in diode region: in progress, in-situ heating planned



‘Premature’ Z-Collapse: Total and Beam Current increase rapidly, and x-ray output (PIN diode) terminates BEFORE END OF POWER PULSE



Shot 1426-1435 4.5 MV 7mm-7mm

Shots 1586-87 7 MV 8.5 mm-8.3 mm

Shots 1674-75 8 MV 12.5mm-12mm

- Each Plot shows Total and Beam current plus (scaled) Forward P-I-N (PIN_4) for three pairs of shots at different output voltages. When Beam current reaches inflection point on dotted curves, P-I-N signal collapses.
- 4.5 MV comparison (LEFT) shows increased Diode and Beam Current for all times for Z-collapse shot. In other two shots, currents look very similar before one of them runs away.

Changing Materials in diode region yields unexpected results

- ‘Standard Diode’: 12.5 mm cathode, 12 mm A-K gap, Al foil 0.7mm from Ta converter. Al foil (adsorbates as presumed ion source) appears to mitigate release of bulk emissions from Ta converter into A-K gap.
- Variations investigated here:
  - Foil changes: Gold and Tantalum foils.
    - Au: rapid Z-Collapse evidently caused by increased foil emission
    - Ta: Can be similar to Al foil, but several shots showed early Z-collapse
  - Coated Ta instead of in-front Foil.
    - Both Al and Au coating result in increased diode current, shortened FWHM
  - Solid Al instead if Foil over Ta converter
    - Behaves like Al coating. All show increased diode current over ‘Reference’.
- Summary: ‘Standard’ configuration is still best performer for FWHM and dose. (Others can have smaller spot size.) Foil reduces effect of ion emissions from bulk converter. Other variations increase bad shot rate.
- NEXT STEP: heating anode in-situ. CAVEAT: If we don’t know the ion source exactly, will ‘cleaning source up’ lead to improved results?

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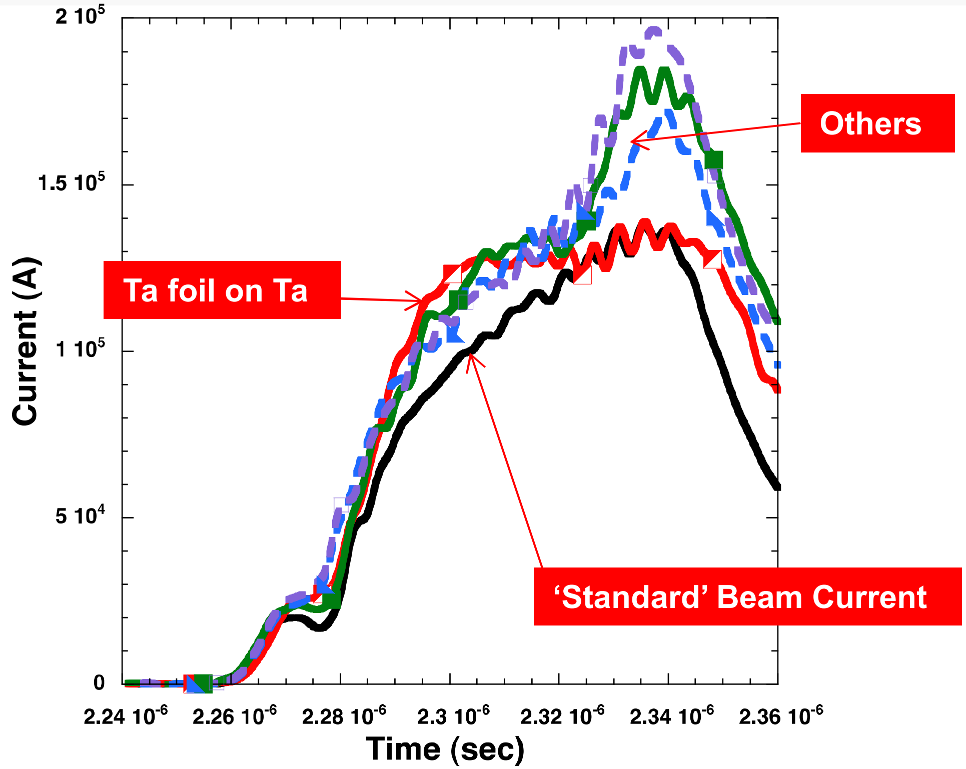
Higher diode current does NOT necessarily lead to Z-collapse



- 'Standard' beam current (black) delayed, and increases more slowly than any other variation tested
- Ta foil replacing Al (red) rises quickest, but then flattens out (slope ~ 0) to EQUAL standard late in pulse (source-limited?)
- 'Others' beam current in-between, then show Z-collapse. Others: Solid Al (purple), Au foil on Ta (green), Al-coated Ta (Blue)

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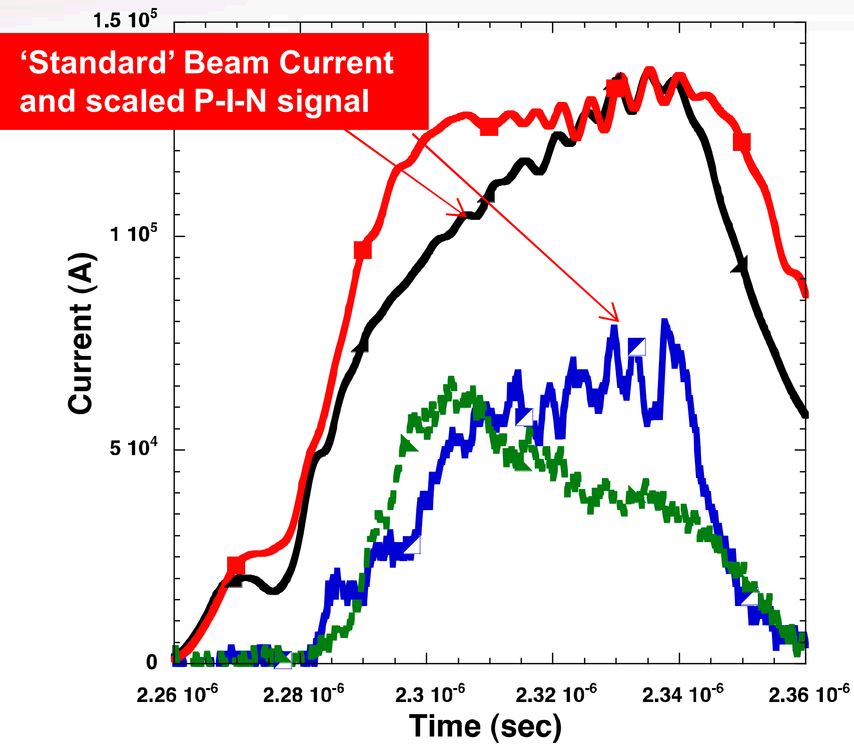
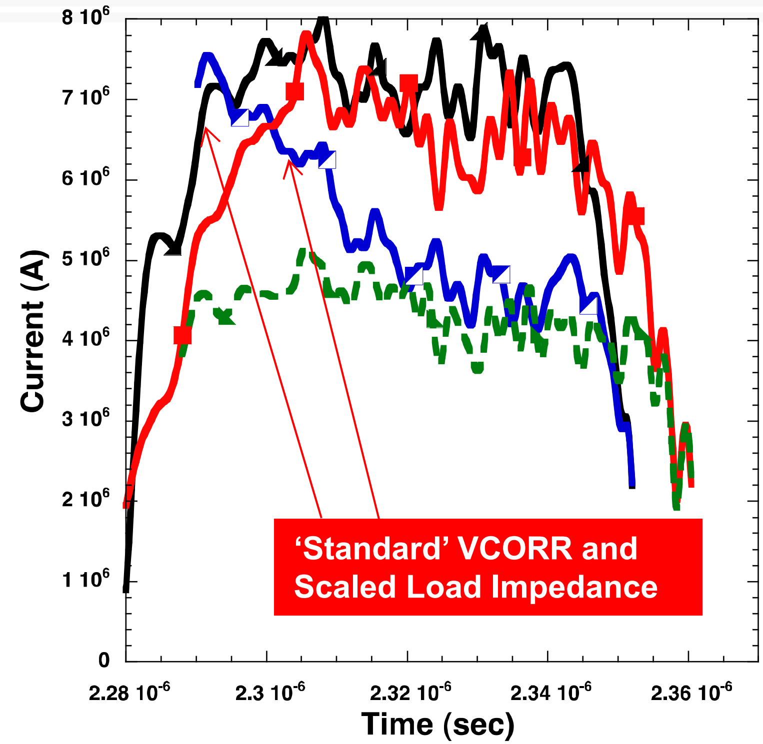
Appears Diode can adjust to initially high current (sometimes)

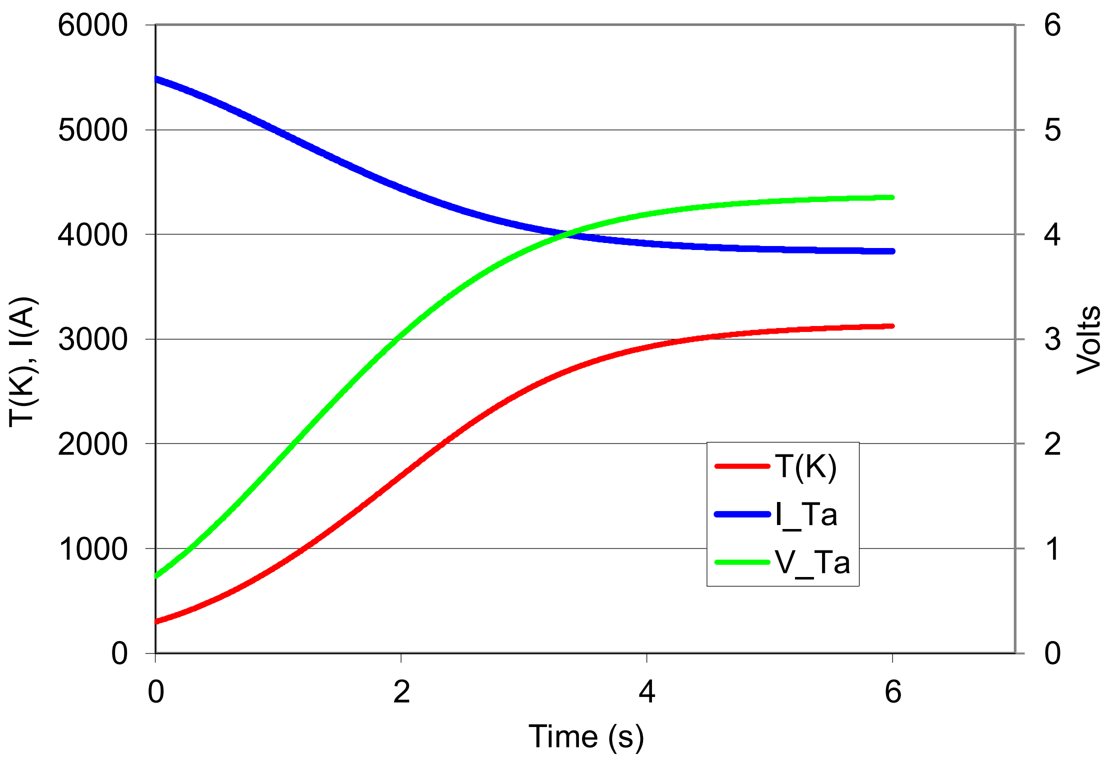




- (LEFT) beam current (black) and (scaled) on-axis P-I-N signal (blue), for standard shot, red and green (respectively) for Ta foil on Ta shot. X-rays from Ta foil shot run higher initially, then lower, suggesting lower voltage later in time. (Dose: 341 Rads@ 1m standard, 299 Ta)
- (RIGHT) Corrected Diode Voltage (VCORR) (black) and (scaled) Load Impedance (blue) for Standard shot, red and green (respectively) for Ta Foil on Ta shot. Ta voltage shifted later in time; initially high Standard Z falls to match Ta foil Z later in time.
- Anecdotal behavior: suggests Parallel Load, rather than electrode plasma closure terminates pulse for 'others'

NRL Pulsed (bulk) heating of converter with batteries: based on previous demonstration of proton reduction and increased (Brems) pulsewidth

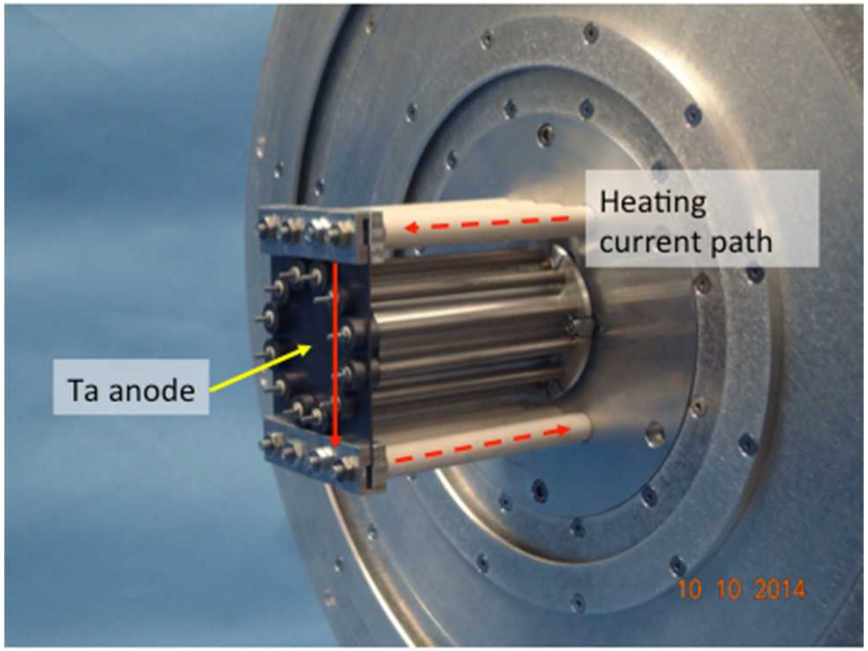
- To be tested on the MERCURY Facility at NRL
- Three 12.8-V batteries connected in parallel
- T > 2500 K for sufficient time for H to diffuse out from interior
- Protocol: pulse once in vacuum, then again ~6 s prior to generator shot
- Prior experience* with larger, thinner Ta foils used similar current for ~ 1 s to achieve:
  - 400x decrease in protons
  - Decreased activation of components
  - Increased dose and x-ray pulse width



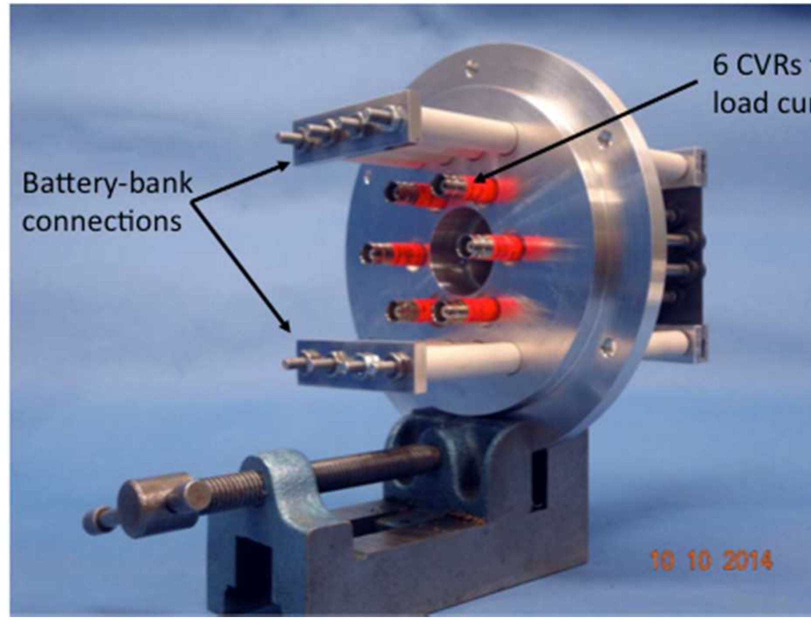
Simulation of Ta converter response to battery heating

* B.V. Weber, *et al.*, "Improved Bremsstrahlung From Diodes With Pulse-Heated Tantalum Anodes," IEEE Trans. Plasma Sci. **30**, 1806 (2002).

NRL heating path is separate from converter support



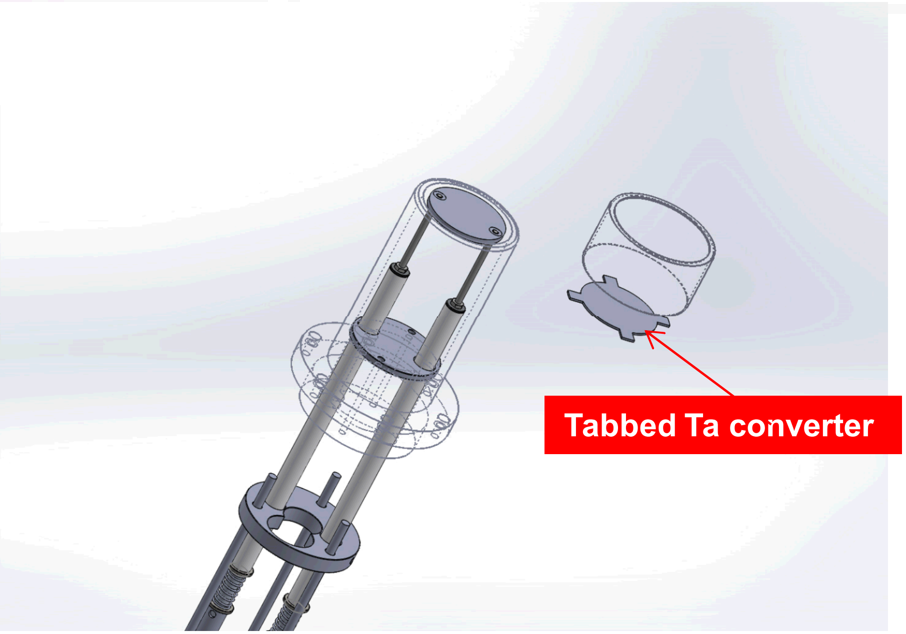
Front View (towards cathode)



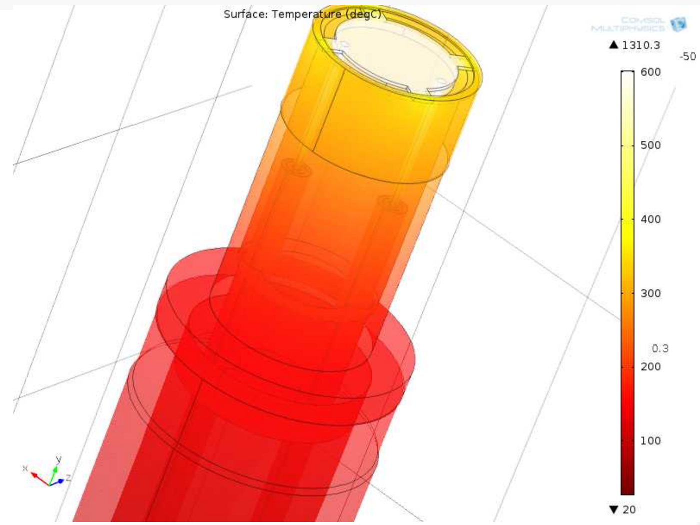
Rear view behind anode

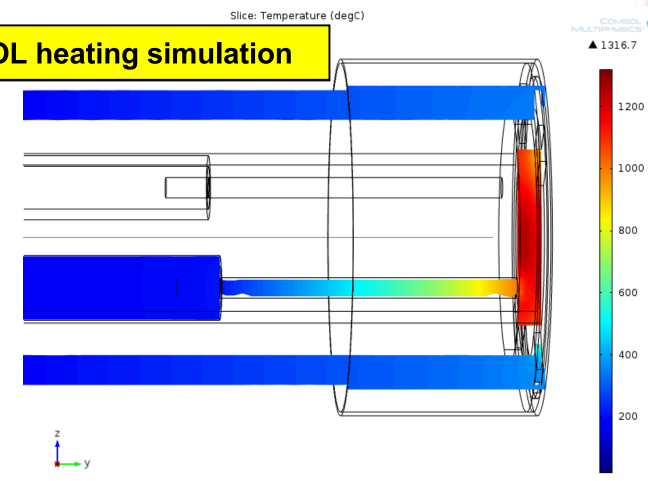
- Ta anode supported by multiple rods in azimuth angled (slightly) away from axis to keep Ta flat during pulse-heating
- Battery current feed rods at top and bottom: current flows top to bottom on converter
- Six CVRs in current path to measure load current

Sandia heating approach: emphasize foil or Al coating on Ta instead of bulk Ta



Overall View of anode assembly





COMSOL heating simulation

- AC heating current (10A, 70 V) brought through vacuum and heats either W filament or W encased in BN
- Converter has azimuthal Tabs to reduce thermal conduction to Al anode case
- Heat Flow Modeling: Ta can reach ~ 1200° C, radiation to free-standing foil allows for ~ 450° C while Al case held to ~400° C
- For Al-coated Ta, heating of Ta dialed back

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Summary

- **At any given output voltage, SMP cathode (K) diameter can be chosen to give stable performance, e.g. high dose, full radiation pulse (FWHM).**
- **Smaller K diameter leads to smaller spot size, but also to**
  - Decreases in dose-rate due to Vload drop caused by low diode impedance
  - Increases in E-Beam pinch angle on the converter leading to lowered dose rate
  - ‘Premature Impedance Collapse’: cause unknown but may be related to above effects
- **We have experimented with materials variation changes (foils, coating, bare converter) in attempt to improve smaller-K performance. So far, all changes lead to compromised ‘Standard’ performance, e.g. reduced dose and FWHM. Appears that Parallel load (e.g. increased electron emission from K sides) rather than electrode plasma closure is source for Z-collapse.**
- **In-situ heating (several designs shown) planned to improve performance at smaller K-diameters.**

Questions?

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