Coaxial Vacuum Gap Breakdown for Pulsed Power Liners

PULSED POWER PLASMAS GROUP

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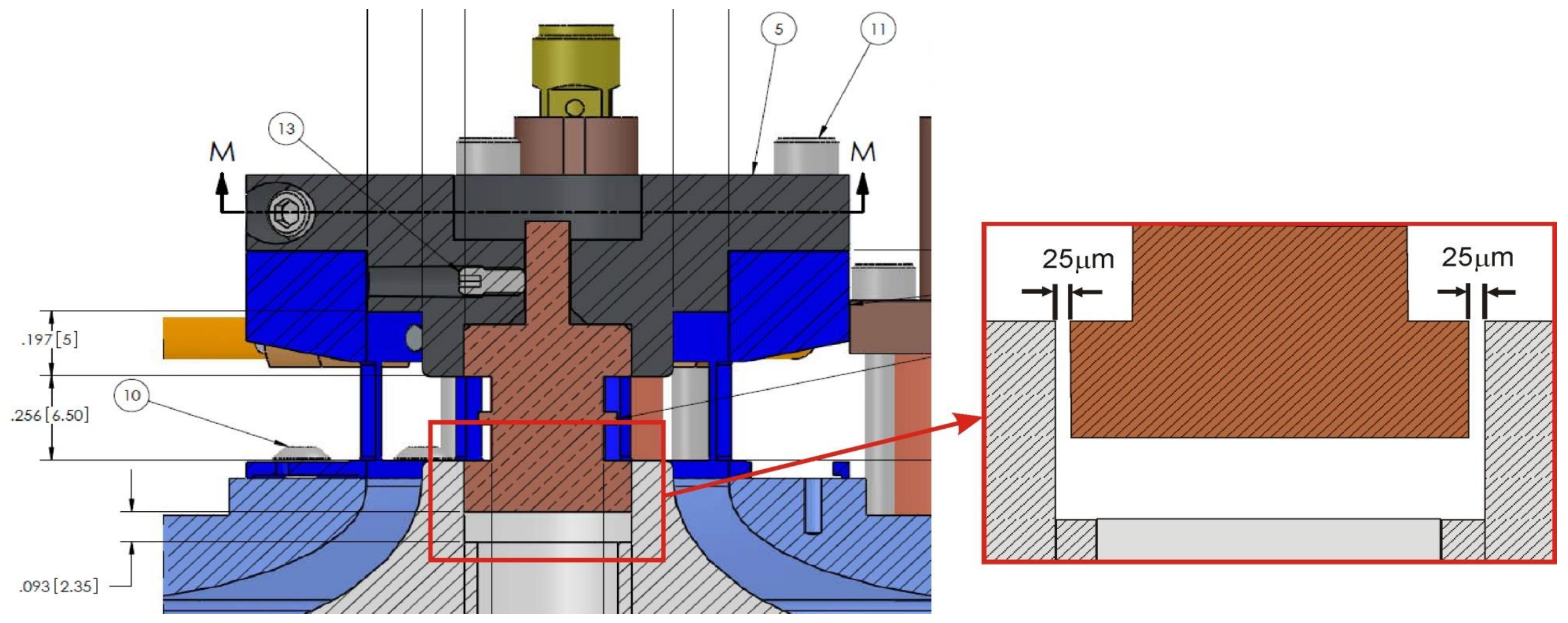
Introduction

This work is motivated by the need to better understand the mechanisms by which breakdown occurs in a coaxial gap over a few nanoseconds to a few microseconds at 10's of kV at gap sizes up to 1mm. We are specifically interested in the breakdown about the azimuth, and the influence such symmetry might have.

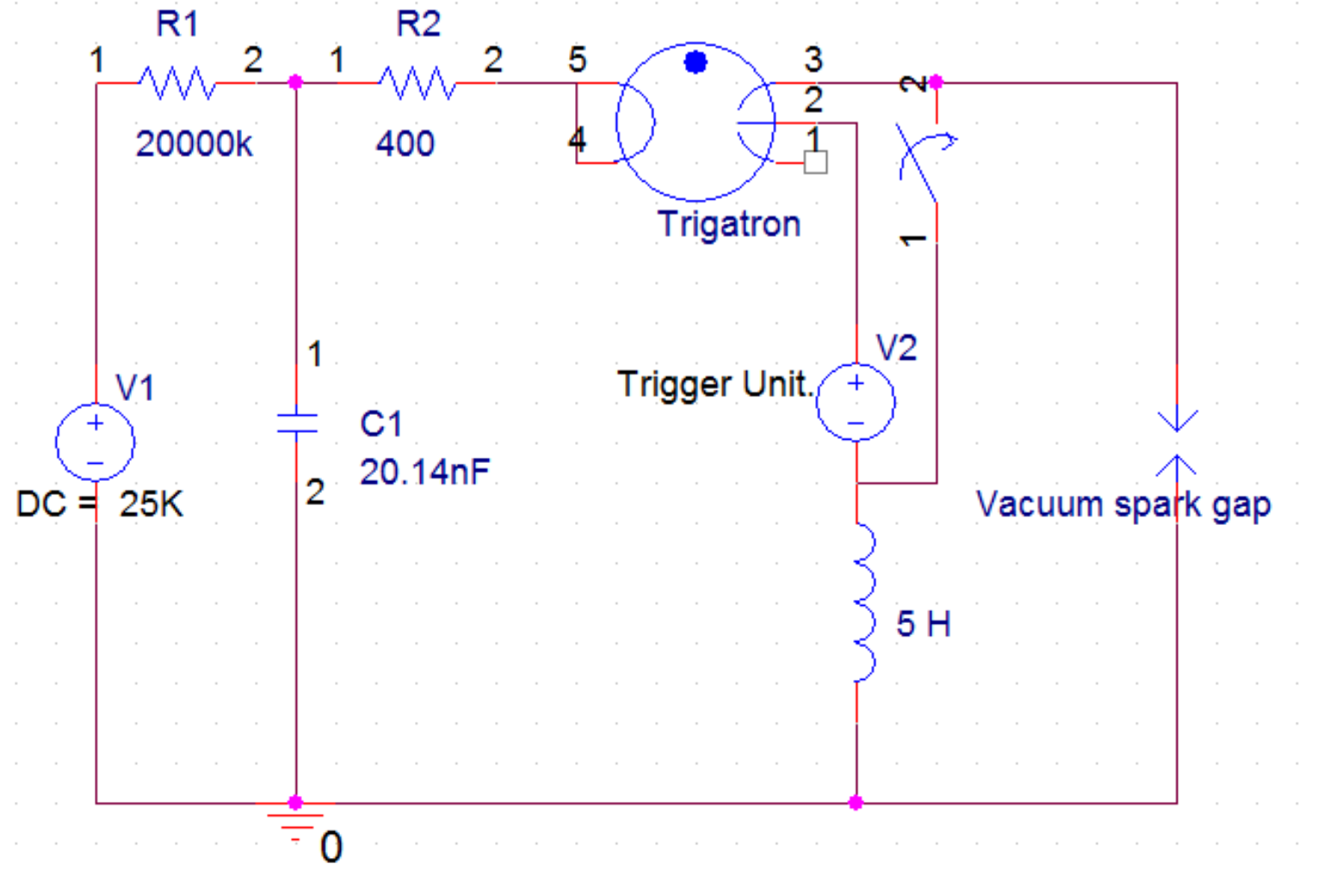
We are developing an experimental system to provide a means of analysis of the mechanism and influences of a coaxial gap.

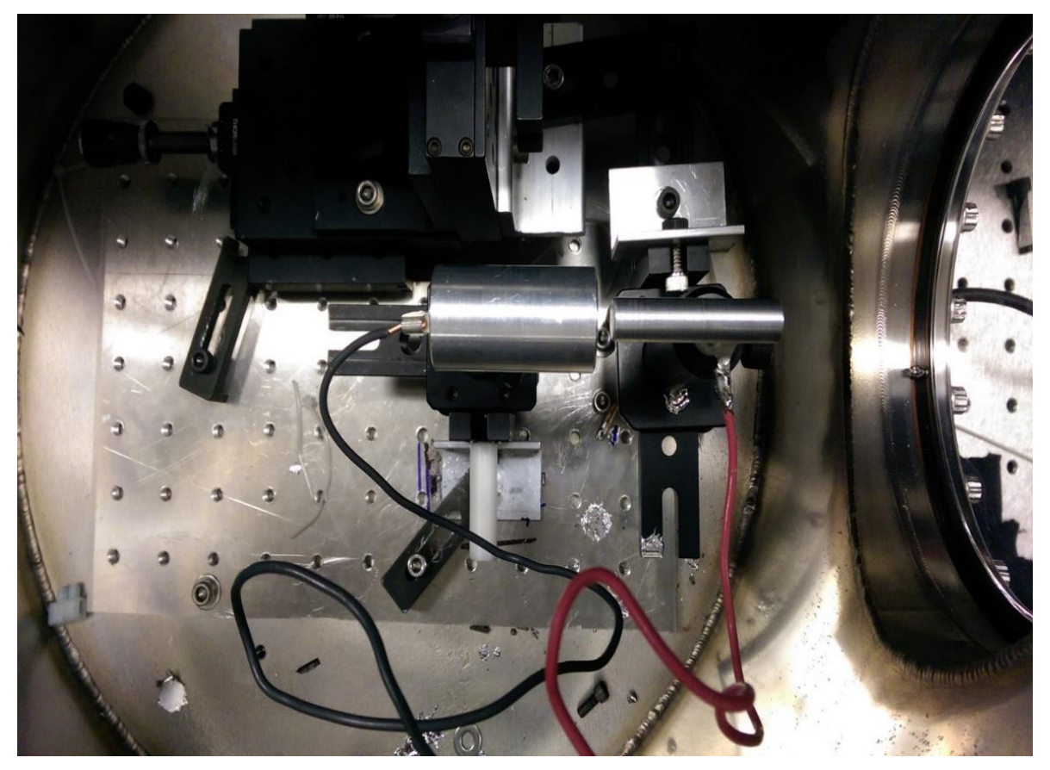
Relevant to MagLIF (Magnetized Liner Inertial Fusion) experiments conducted on the Z-Machine (et all) at Sandia National Laboratory, Which are using a gap in the cathode power feed.



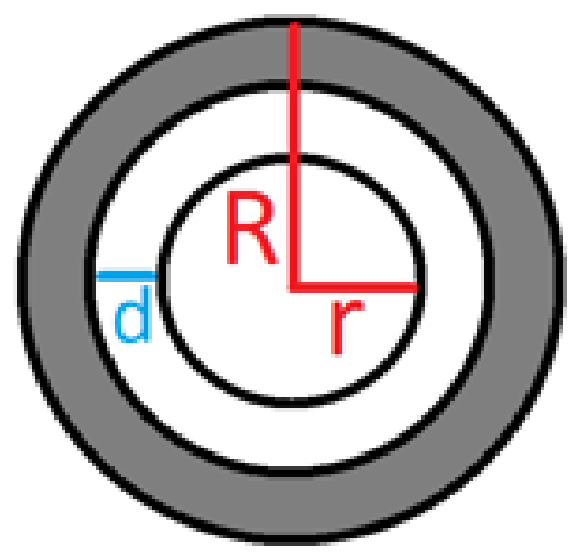
- Image of ~26 MA Z- Machine (Sandia Labs), which uses the coaxial gap for liner loads.

Experimental Design





- Experimental parameters: V ~25kV, 240 A, T_{rise}~100ns, p~10^{-5}Torr.
- Material : Aluminum, not highly polished.
- Gap current measured with Pearson coil model 6585 (1.5ns risetime)
- Gated optical imaging via MCP.
- Laser Imaging: Mach-Zehnder interferometry, 532nm, 0.4ns.
- Magnetic field measurements: Three B-dots (Figure 1.)



- R = 12.665 mm
- r = 5.185 mm
- d = 0.94 mm

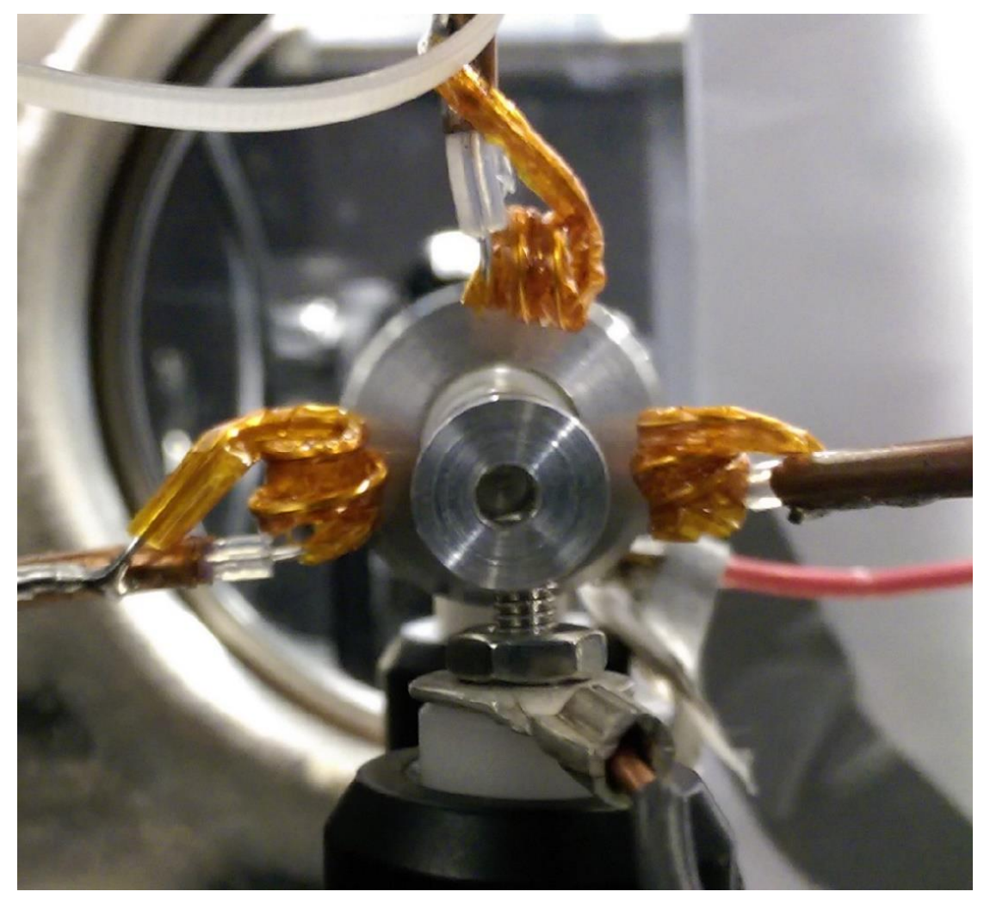


Figure 1 : Mounted B-dot probe positions

Experimental Results

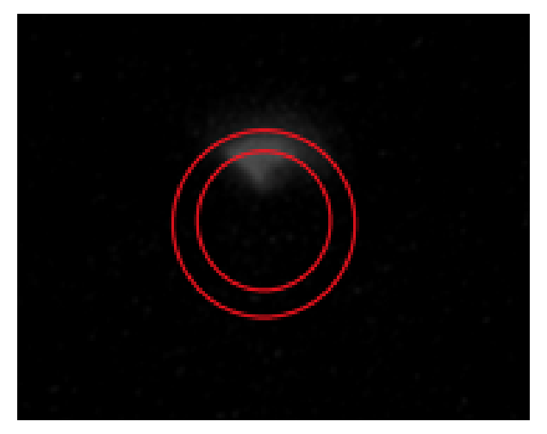


Figure 1a : Gated optical image

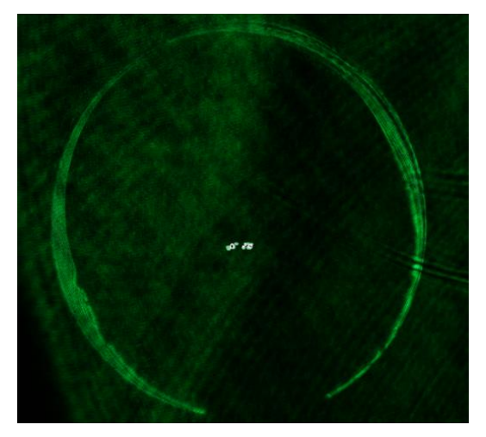
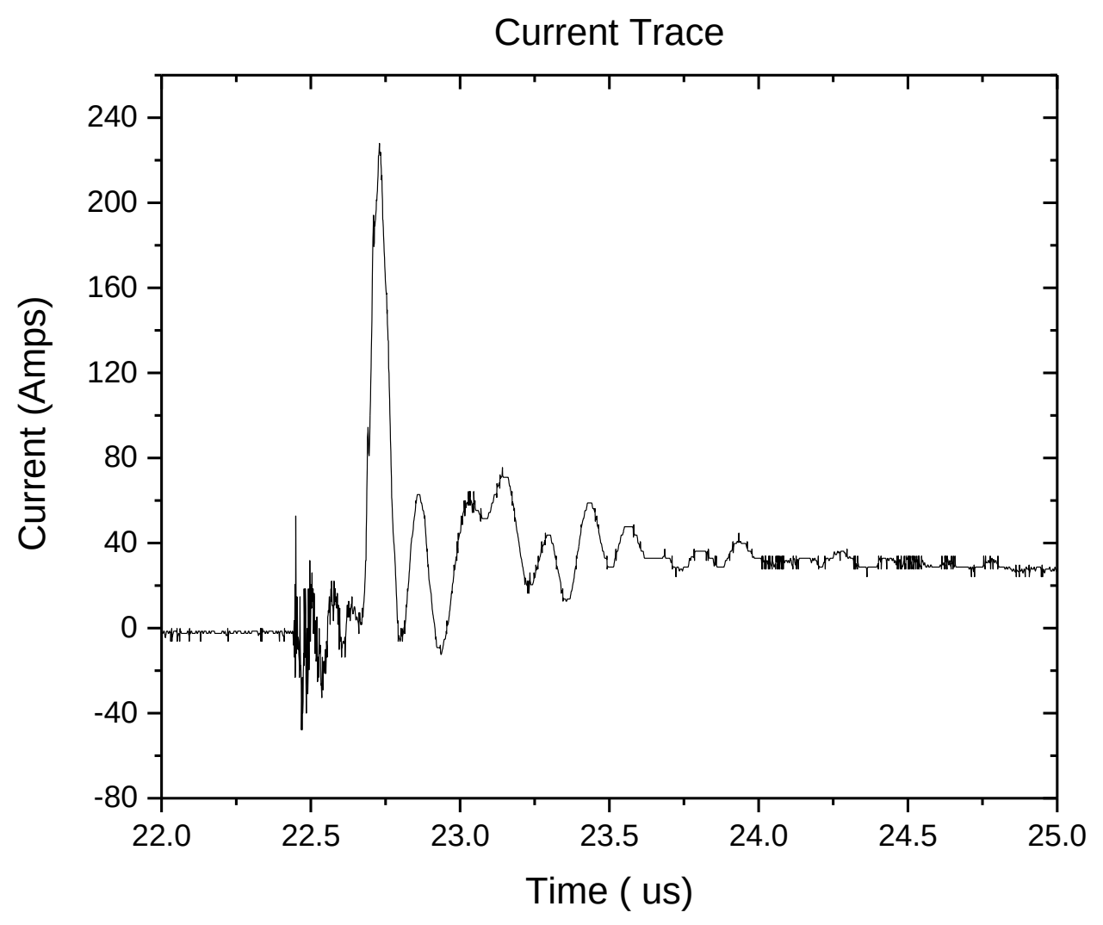


Figure 1b : Laser Interferogram

Figure 1c : Integrated Digital SLR



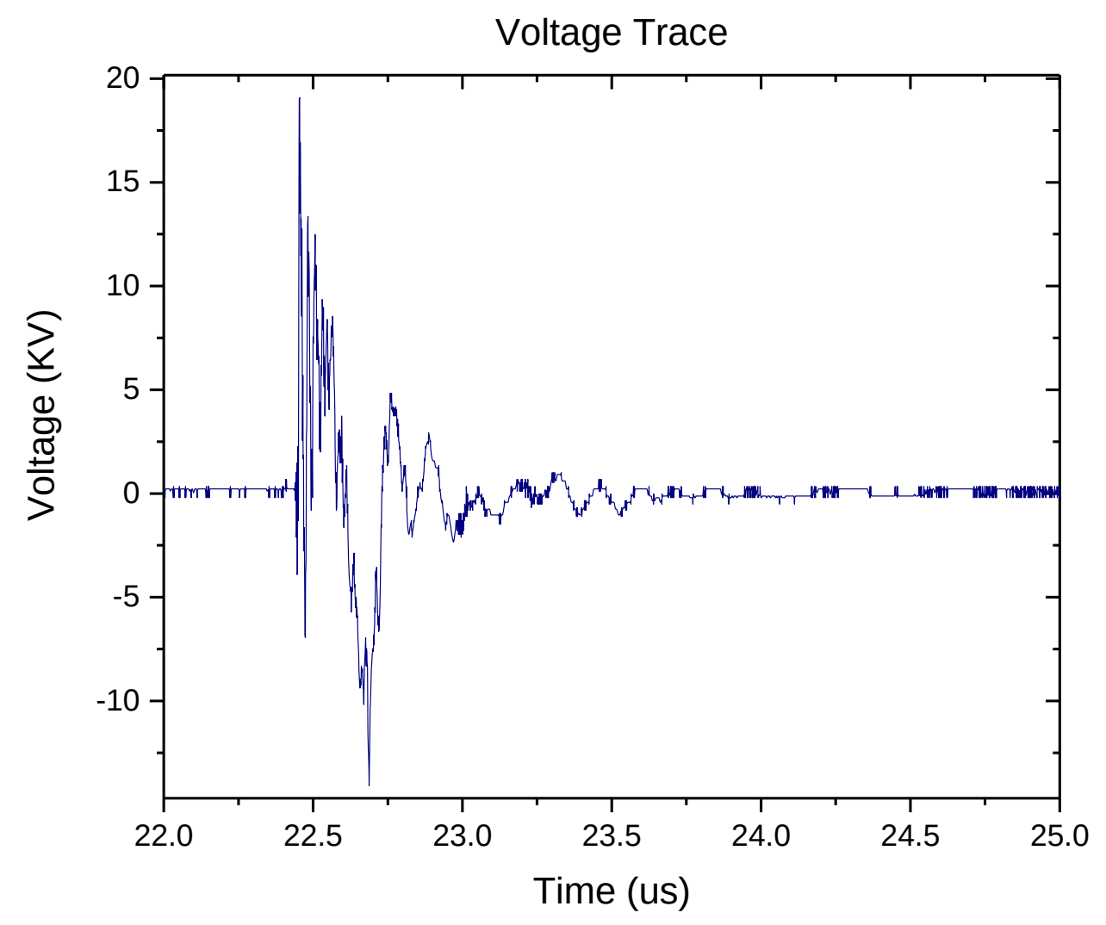


Figure 2a : Integrated DSLR

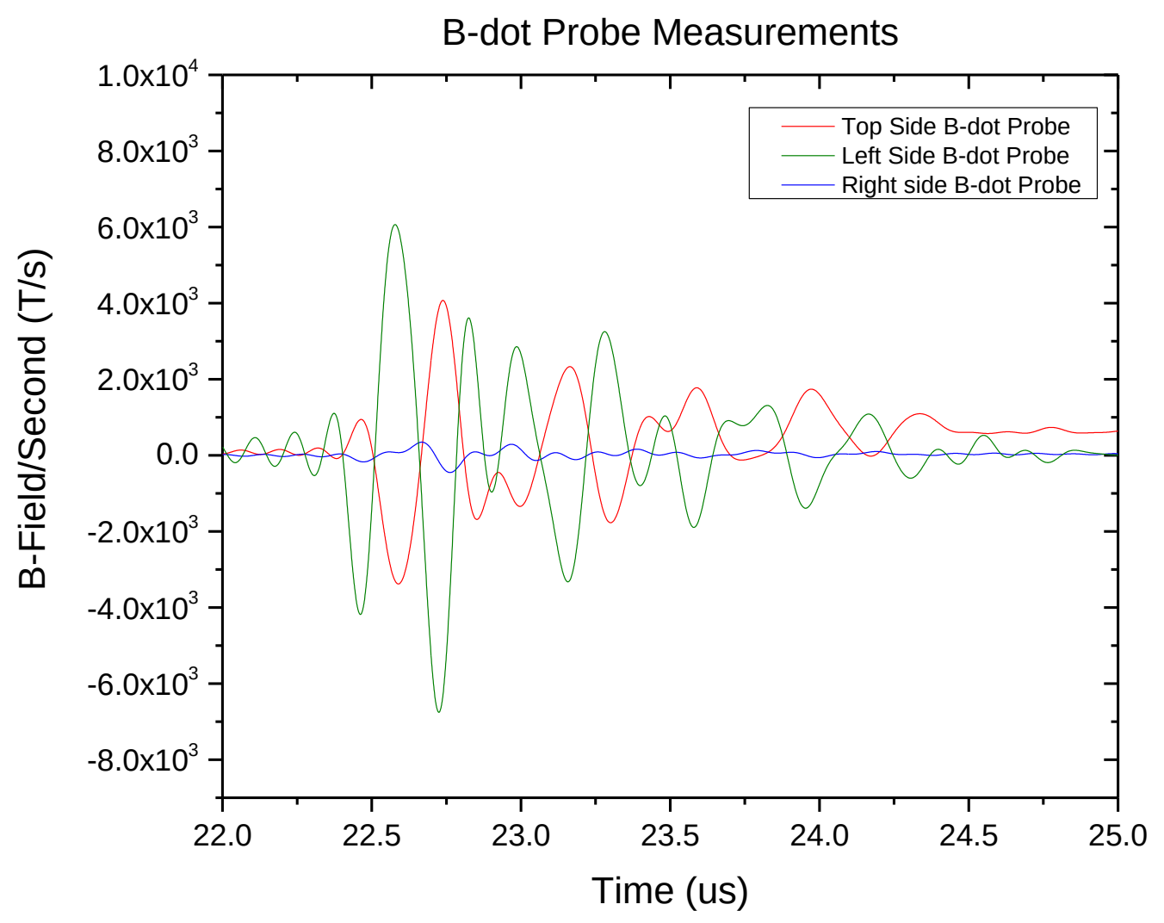
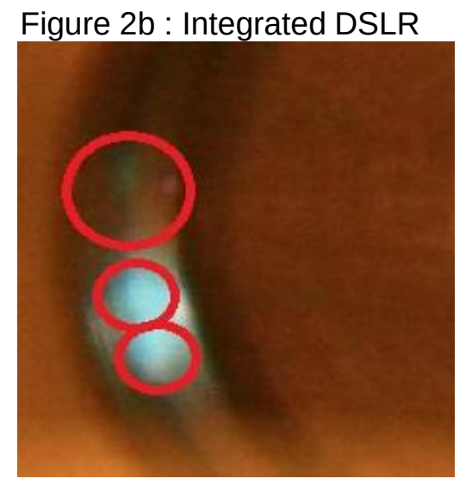
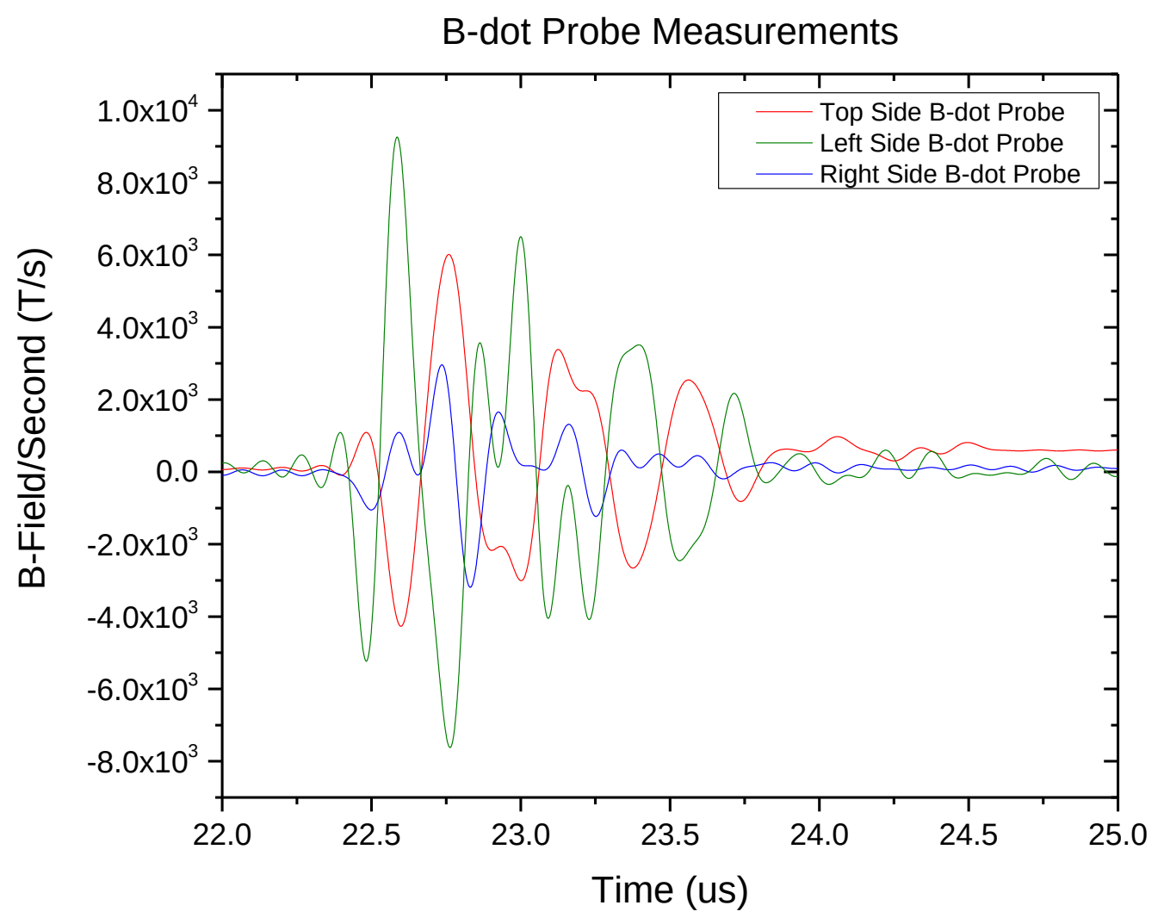


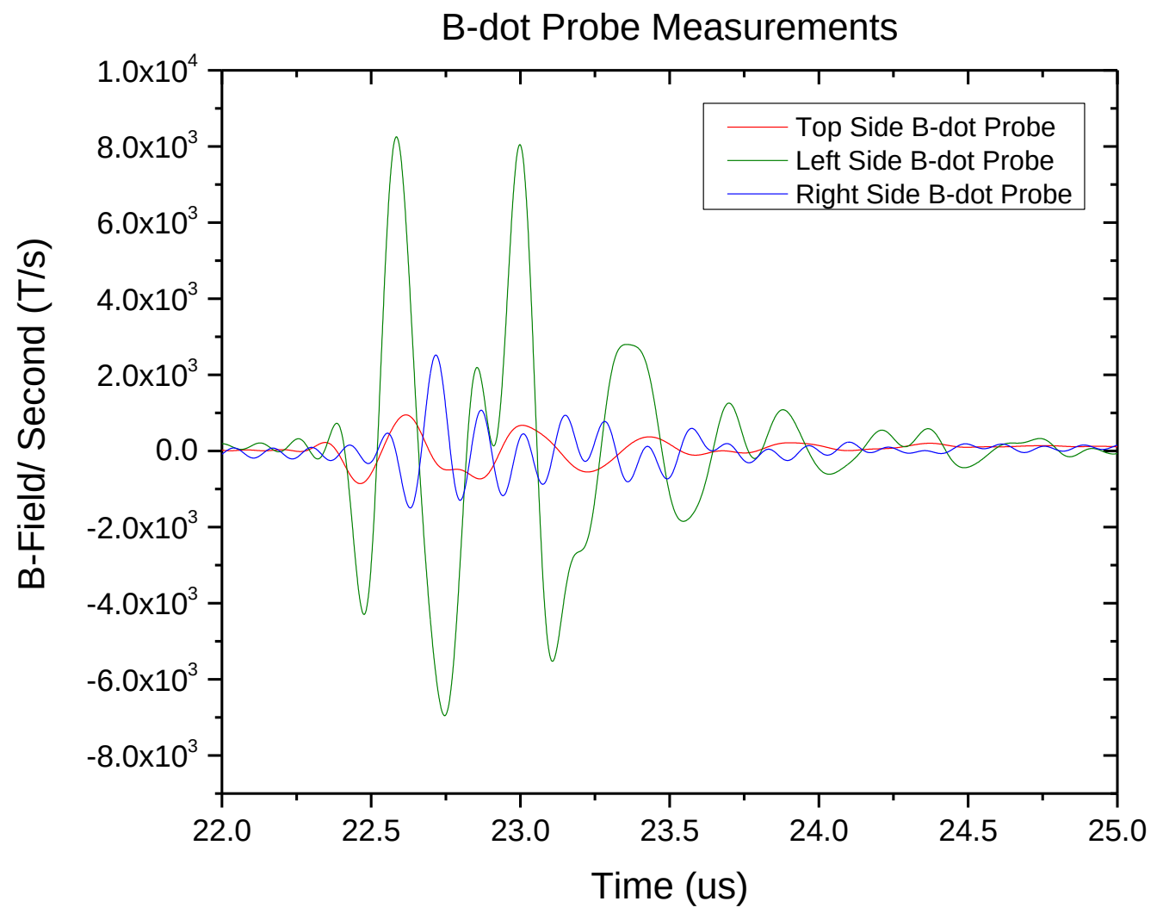
Figure 2b : Integrated DSLR





- Notice the apparent multiple breakdowns in integrated Digital SLR image above, this could explain the slightly larger signals on the top side and the right side.

Figure 2c : Integrated DSLR



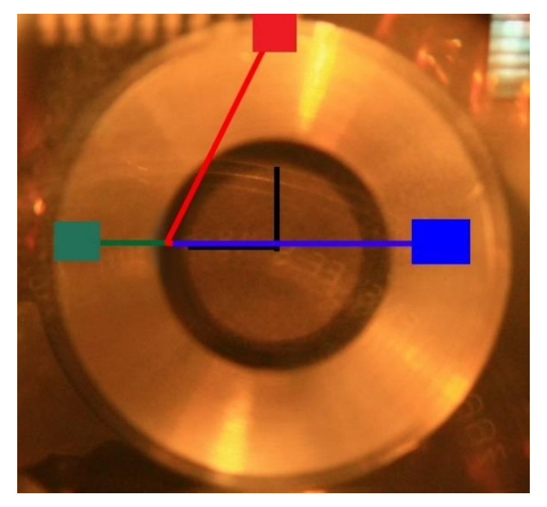


Figure 1a : Triangulation DSLR

Breakdown triangulation:

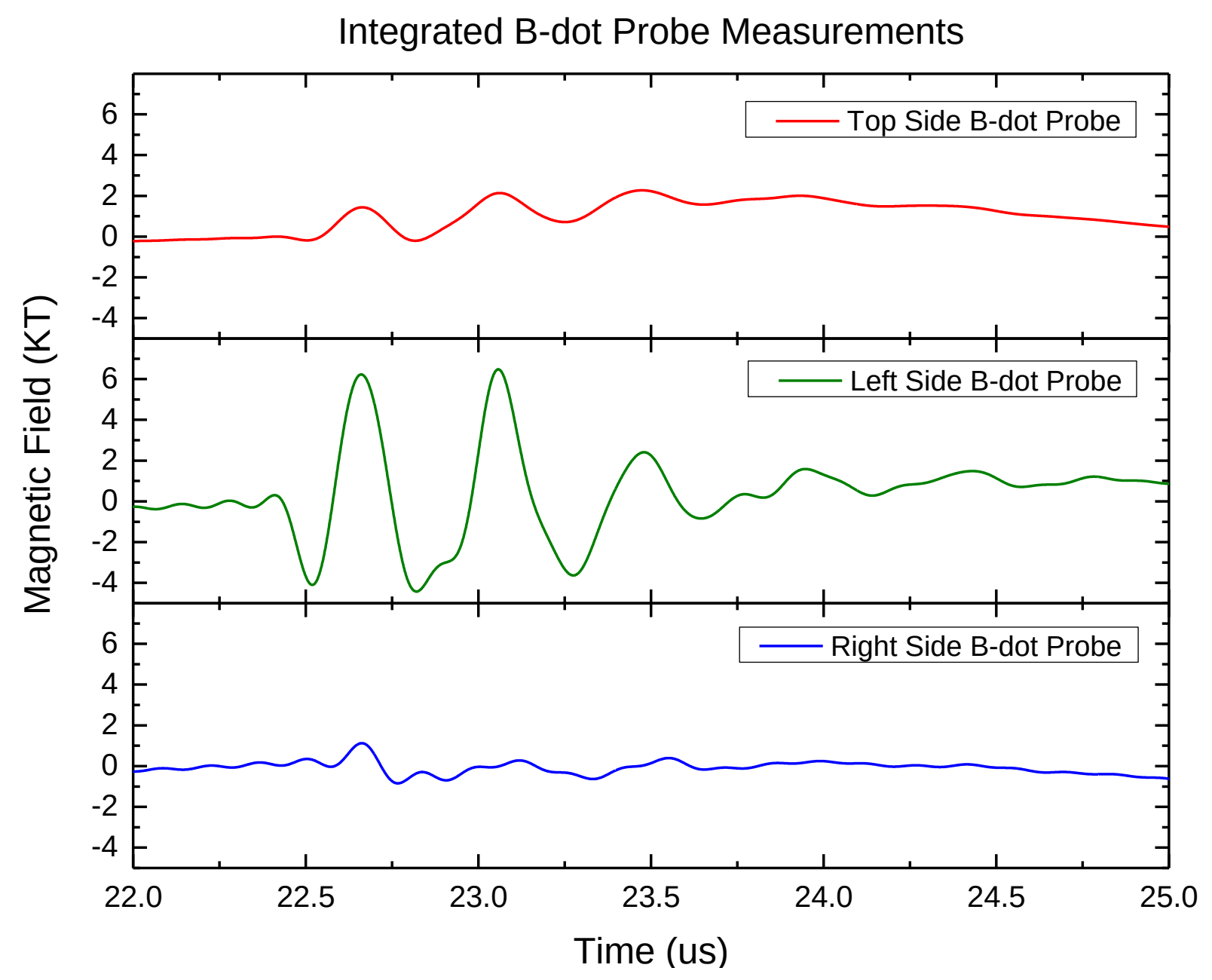
Can use ,$R = \frac{\mu I}{2\pi B}$, for each peak B-field value (on the right) to estimate the corresponding distance from break down. The R value corresponds to the distance the breakdown is from the probe.

- Peak Current (I): ~220 Amps

- Max B-Field-Left Side Probe:~6.44E-3 T
- Calculated R: 6.83 mm

- Max B-Field-Top Probe:~2.09E-3 T
- Calculated R: 21.05 mm

- Max B-Field-Right Side Probe:~1.7E-3 T
- Calculated R: 25.88 mm



- With the 3 calculated R values we are able to Triangulate the position the breakdown has occurred at. Which in this case occurs on the left side.

Experimental Summary

Coaxial:

- Random breakdown about the azimuth, when parallel.

B-dot Measurements:

- The largest magnetic field strength is measured on the probe(s) closest to where breakdown occurs (as seen in the integrated DSLR images compared to dB/dt signals).
- Able to accurately determine location of breakdown based on B-field strengths

Laser Imaging:

- Plasma density too low for detection on interferogram. $N_e\ dl <$ 5e16 cm^2

Breakdown Mechanism

The power-feed gap is 25µm – 1000µm, and initially at vacuum (< 5x10^{-5} torr) and room temperature. The load voltage is applied cross this gap which causes electron and/or plasma emission, closing the gap and allowing the main drive current pulse to flow.

Two possible mechanisms by which such an initiation can occur:

Thermionic emission: estimated by the Dushman-Richardson formula.

$$j_T = A_0 D T^2 \exp\left(-\frac{e\varphi}{kT}\right) \qquad (\text{A}\ /cm^2)$$

- Since Liner and cathode are both initially at room temperature, contribution is negligible.
- Electrode skin depth (order of 100 µm for initial pulse, and 1mm subsequent pulse) coupled with the short pulse width (~70 µs) means temp change due to Ohmic heating is of order a few Kelvin.

Field emission is likely the dominant mechanism. As estimated by the Fowler-Nordheim formula.

$$j_F = 6.2x10^{-6} \frac{(\varepsilon_F/\varphi)^{1/2} E^2}{\varepsilon_F + \varphi} \exp\left(\frac{-6.85x10^7 \varphi^{3/2} \zeta}{E}\right) \qquad (\text{A}\ /\ cm^2)$$

- Proportional to the work function of the metal surface and the applied electric field.
- Metal surface purposely not polished, results in field enhancement.
- Expect number of channel to be dependent on gap voltage (c.f. rail gap breakdown)

Improvements

- Increased spatial resolution in optical imaging to determine if multiple breakdowns are sequential or coincident
- Voltage probe inside chamber to measure voltage at gap to correlate to current pulse, and breakdown delay
- Investigating various surface finishes and/or electrode materials.

Future Work

- Implementation of Breakdown Triangulation method on larger scale experiments on COBRA at Cornell University.

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