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An experimental apparatus and diagnostics for the characterization of high-voltage surface flashover in large-scale pulsed power conditions

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Motivation

- Characterize anode-initiated flashover in vacuum
  - Engineer a repeatable flashover location
  - Explore and identify the indicators of the breakdown event
  - Measure breakdown with a high degree of accuracy

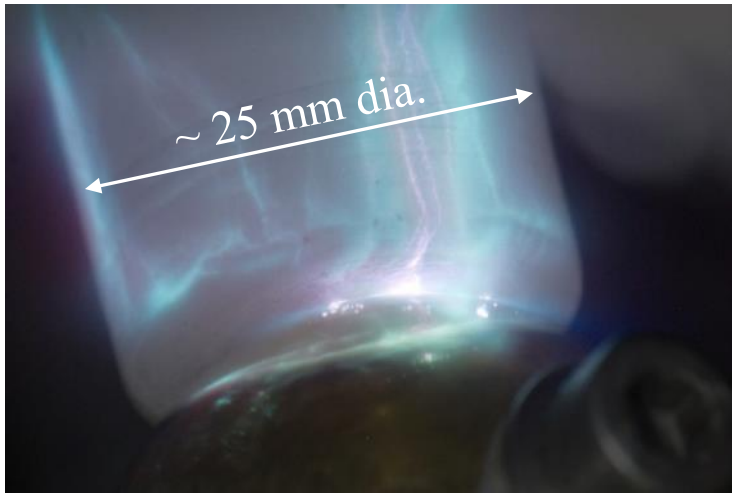
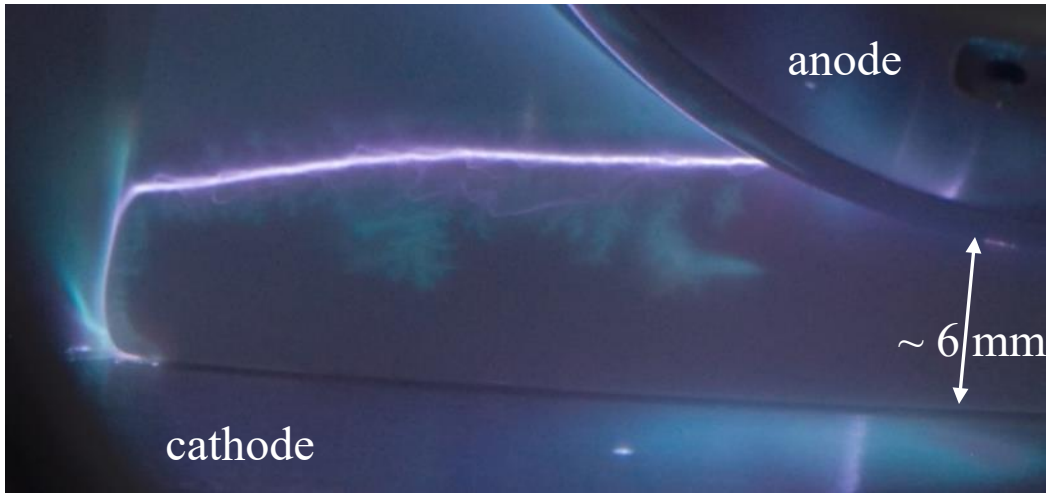
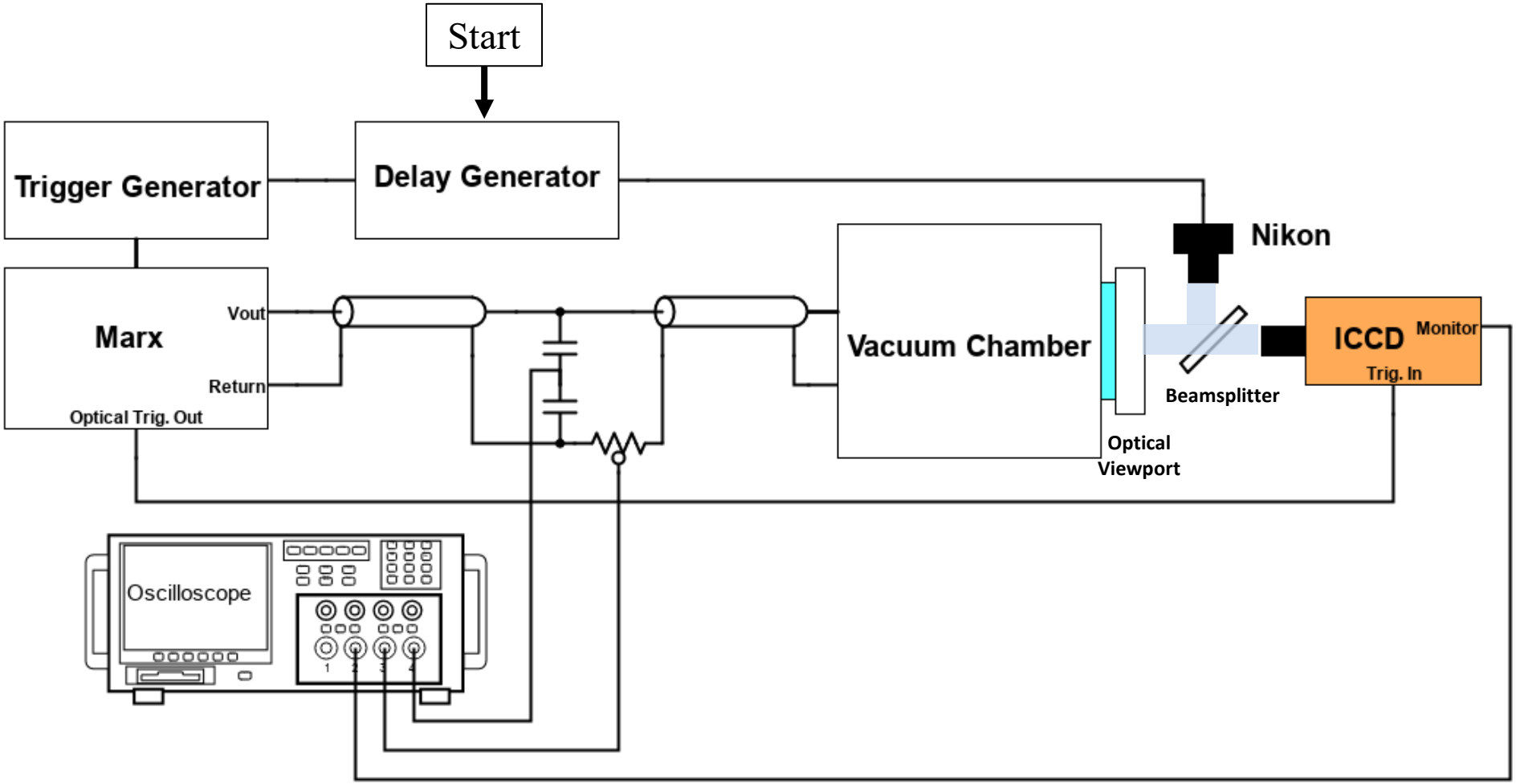


Image of pulsed breakdown of high-voltage vacuum feed-though initially used in experimental setup. (~ 240 kV)



Time integrated image of lateral surface flashover with branching primarily reaching towards the cathode. (~ 240 kV)

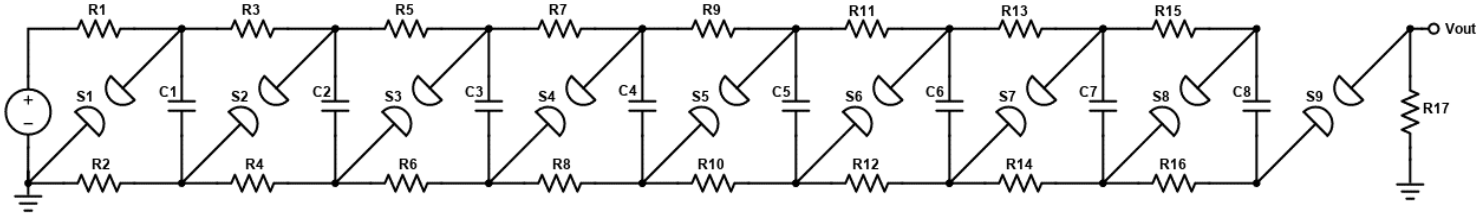
System Overview



Marx Generator (Source)

Pressurized Marx
- 16 psig N_2
- Triggered First Gap
- 8 Stages
  - 5.4 nF / Stage
- 675 pF Erected
- Negative Charge
  - Typical $(-)30$ kV
- Positive Discharge
  - ~18 ns Rise Time
  - $>$ 180 kV Output

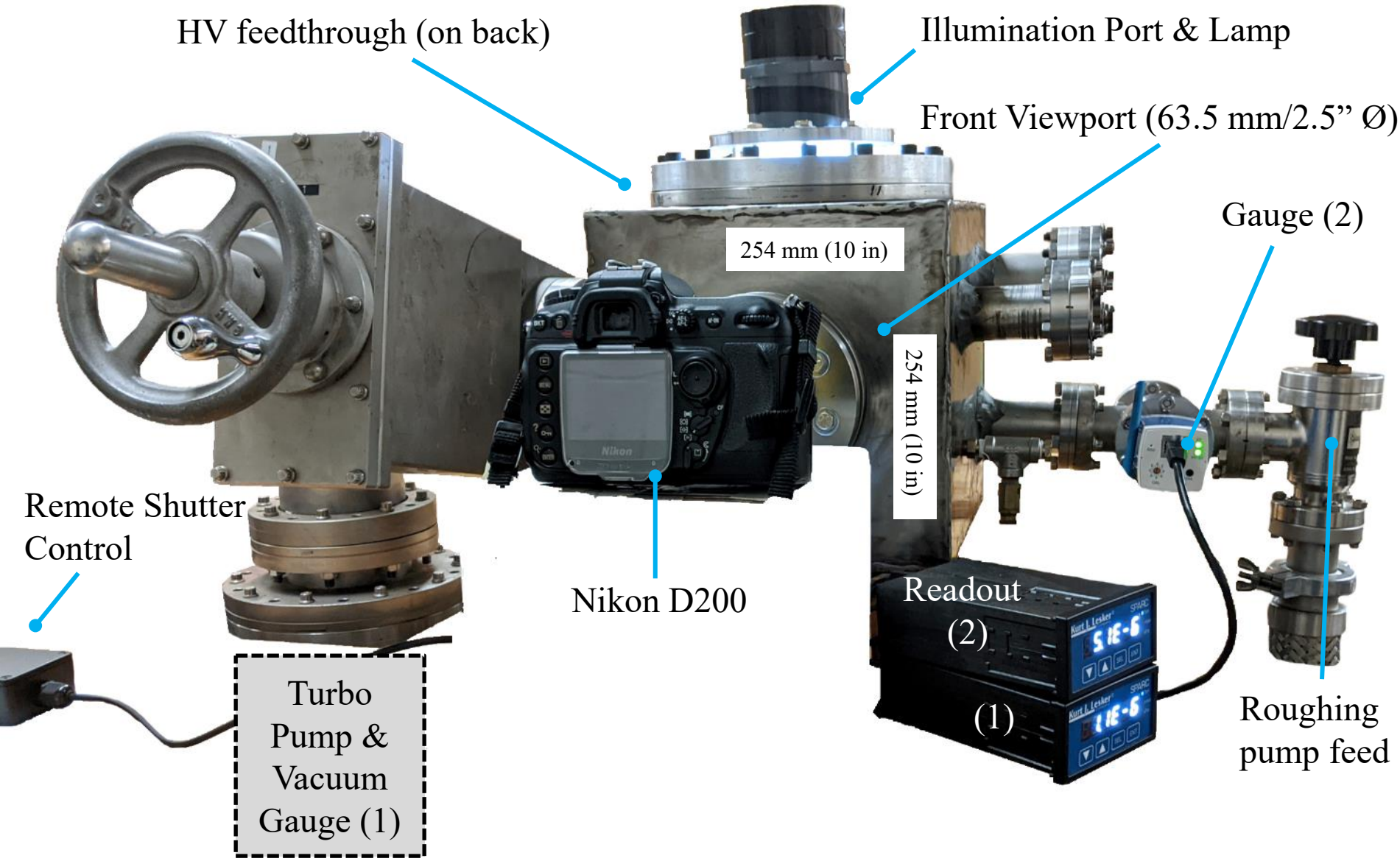
Output
- Internal 2.2 kΩ Shunt
- (System) ESR 30 Ω
- (System) ESL 1.8 µH



Top: Selected Image of Marx Generator

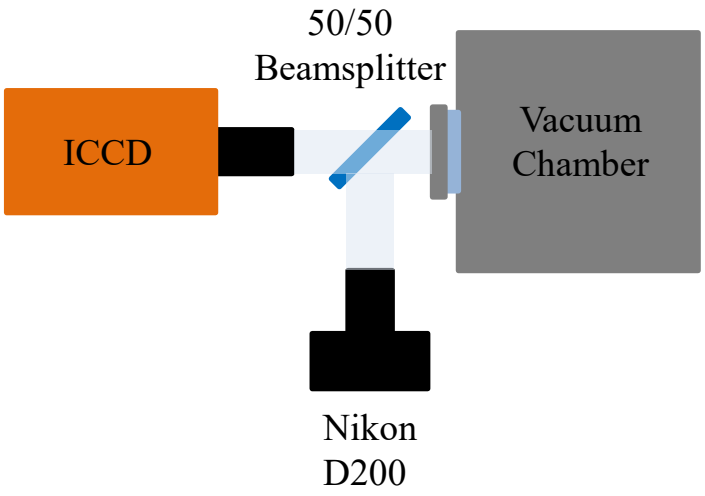
Left: Corresponding Schematic

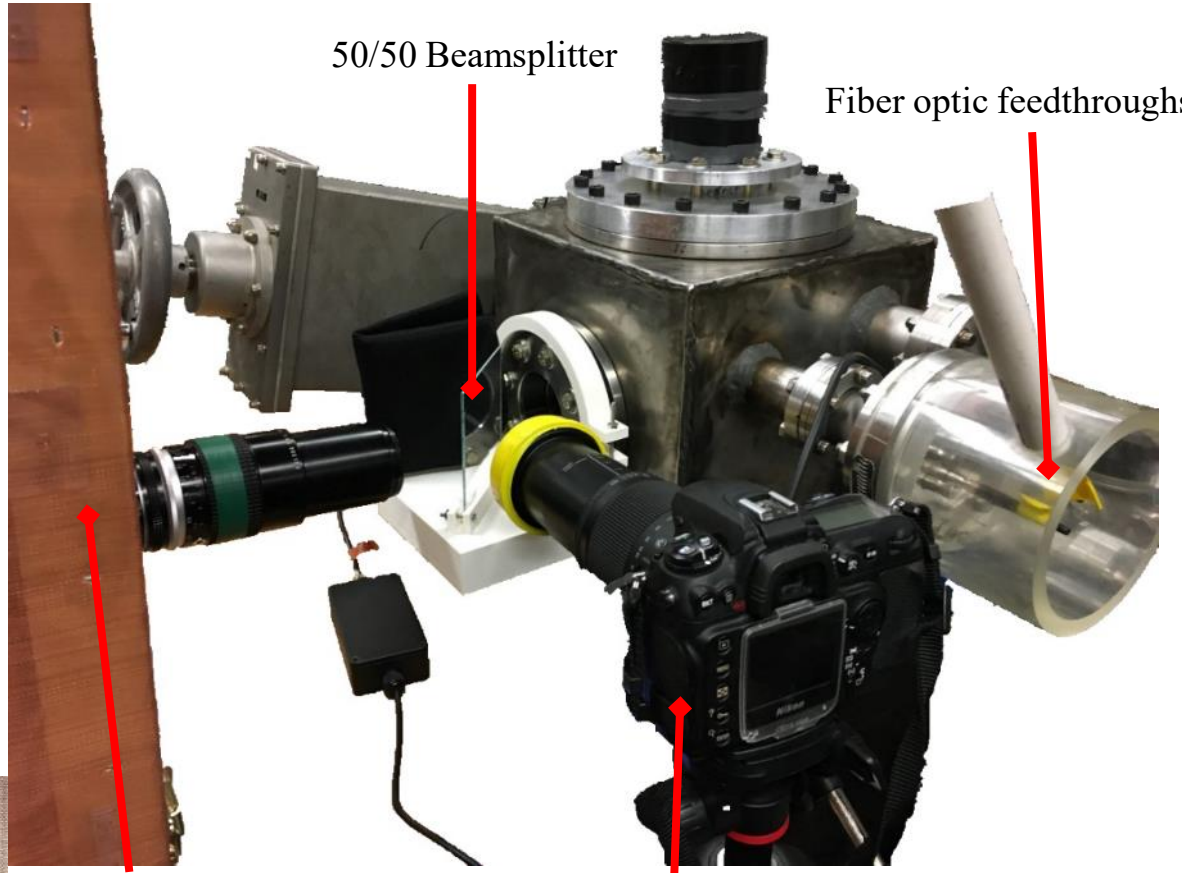
Flashover Chamber (R.0)



Optical Imaging Apparatus

Top-Down View of Imaging Apparatus





Princeton Pi-MAX 4
- Intensified CCD
- Sub-500 ps gate capable

Nikon D200
Sigma 18-300 mm F3.5-6.3 DC Macro
Edmund Optics 75 mm x 300 mm FL
(VIS 0 Ar. Coated, Achromatic Lens, 88-594)

Current and Voltage Diagnostics

Current Viewing Resistor
~ 50 mΩ

Capacitive Voltage Divider

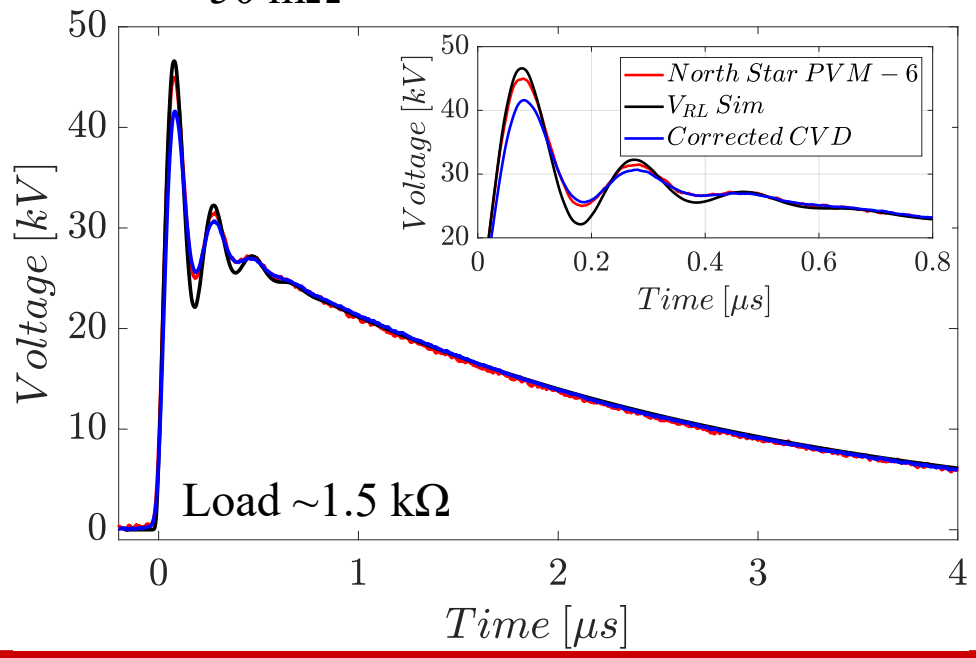
CVR Calibration

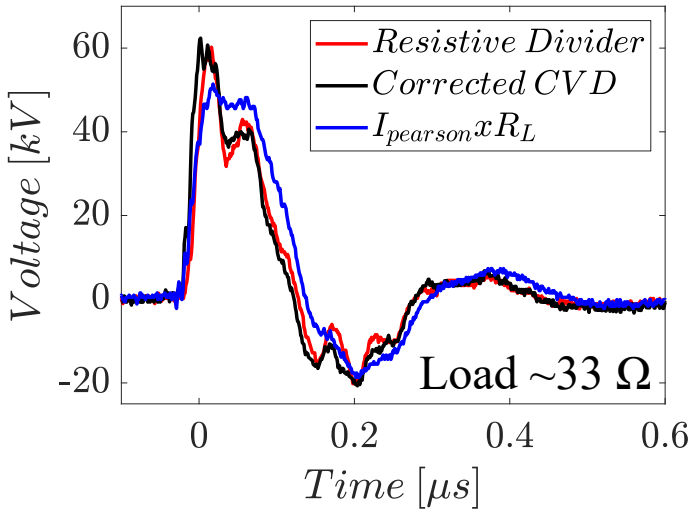
- Pearson 110
- Pearson 6585

CVD Calibration

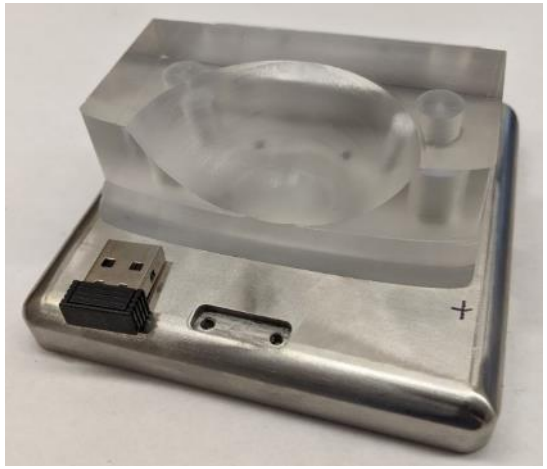
- NorthStar PVM-6
- Current * Load

$$V_{in}(t) = \frac{1}{a}V_m(t) + \frac{1}{\alpha\,\tau}\int_0^t V_m(t')dt'$$





Insulator Testbed



Physical Dimensions

Insulator

79.38 mm (3.125 in) Wide
25.40 mm (1.00 in) Tall

Wedge

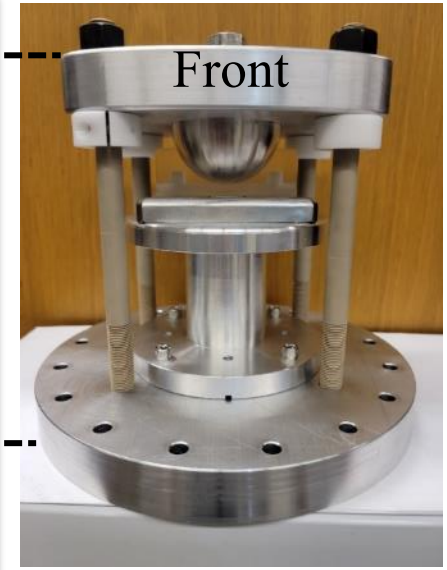
45 Degrees
6 mm Vertical

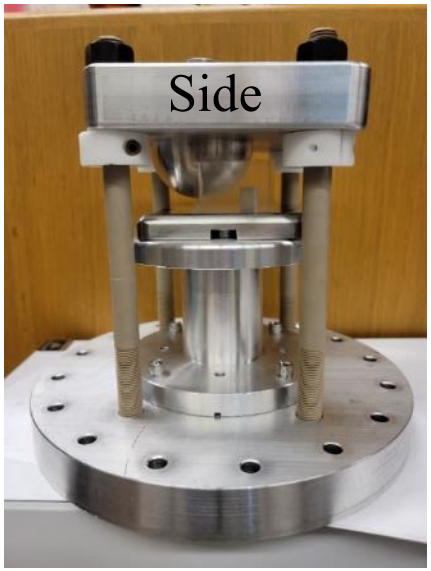
Anode

30 mm radius

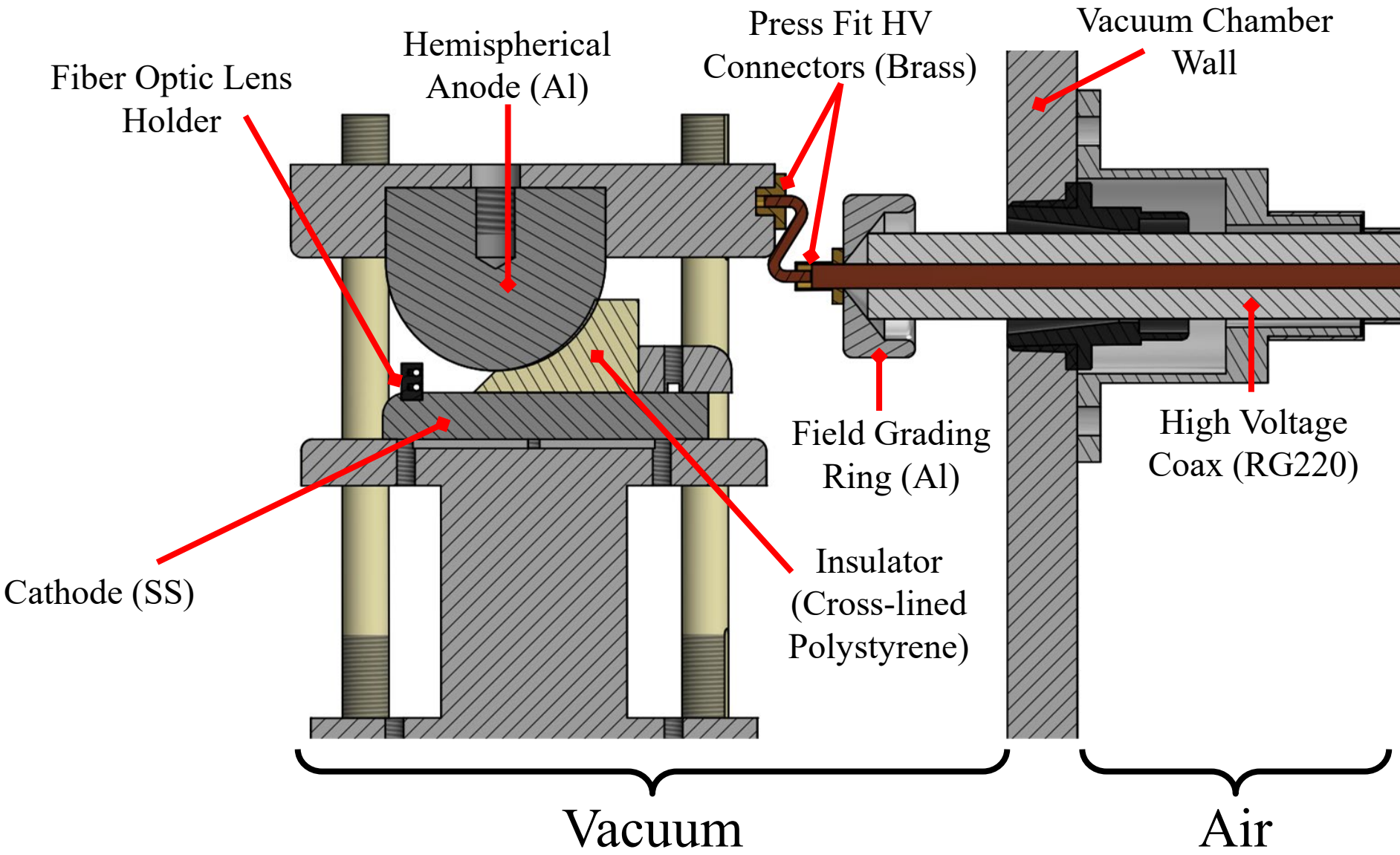
Cathode

95.25 mm (3.75 in) Wide
88.90 mm (3.50 in) Deep



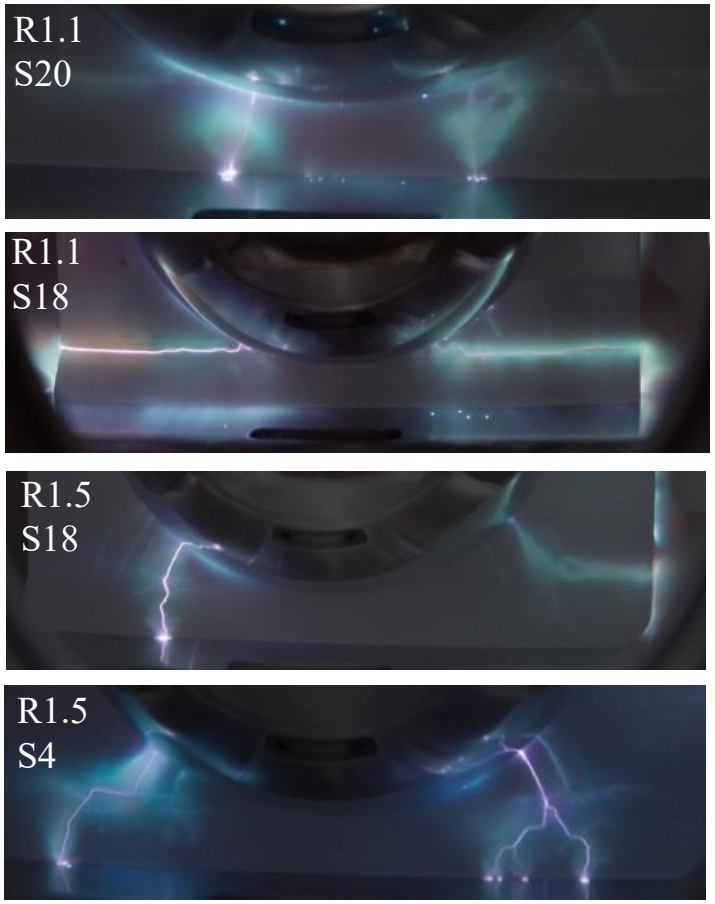


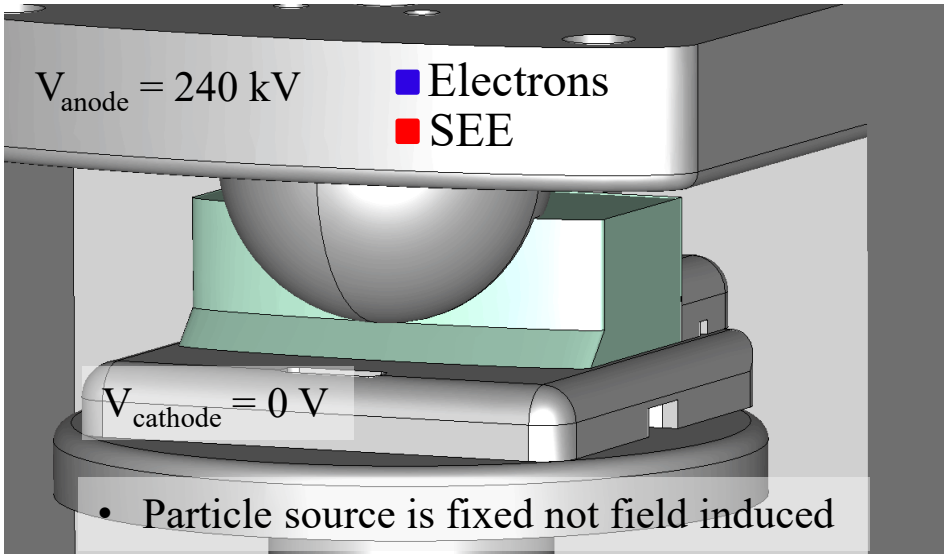
Insulator Testbed Cross-Section

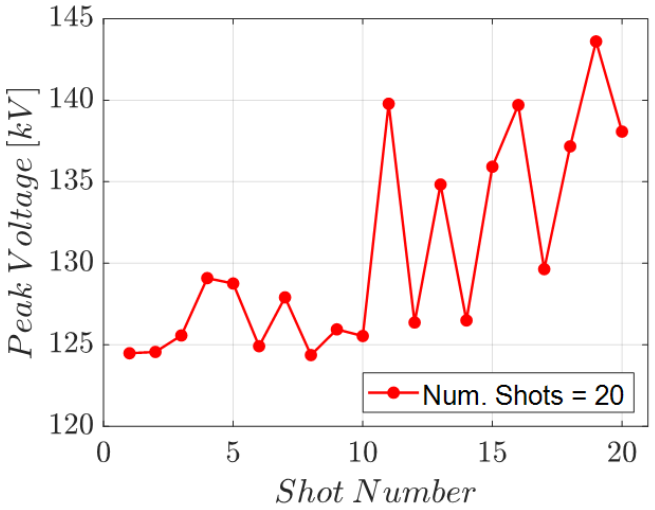


1st Gen. Insulator Topology

- Initial results exposed design limitation, SEEA along front vertical face, in the first iteration of the insulator topology

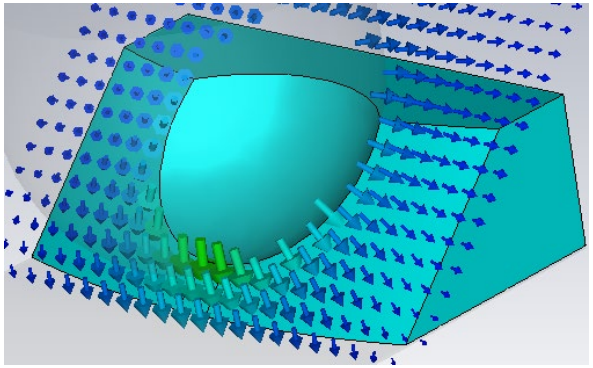




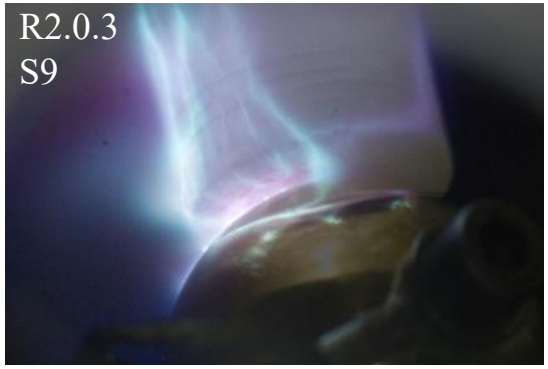


2nd Gen. Insulator Topology

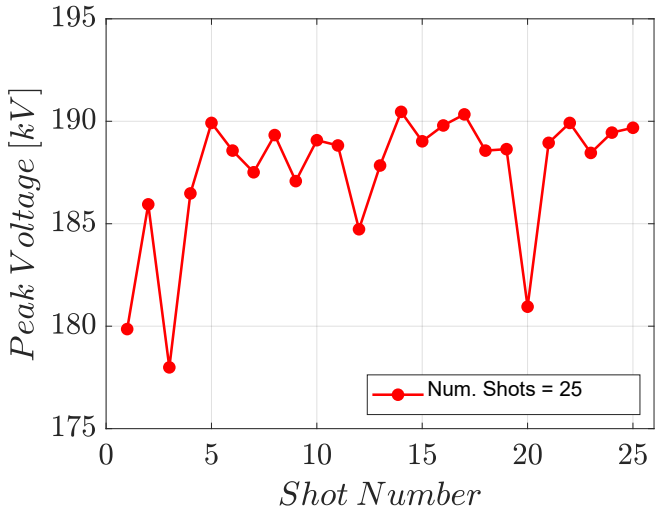
- Second insulator topology pushed breakdown voltage much higher and exposes limitation of the current insulator apparatus



(Simulated) Electric Field

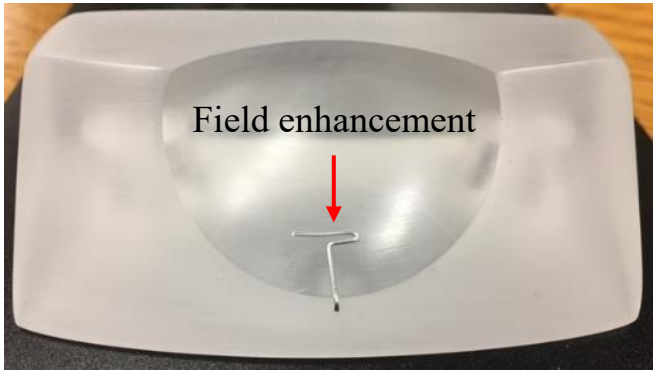


Breakdown along HV feedthrough



Field Enhancement

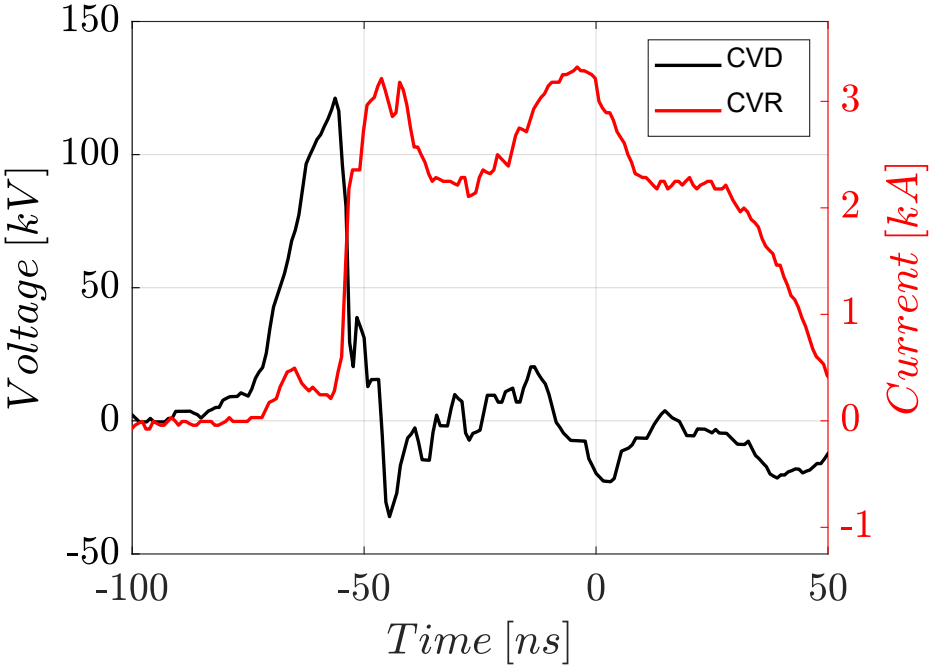
- Field enhancement at anode triple junction simulates a preferential breakdown locations due to a flaw
- Material: Aluminum wire 0.02” diameter



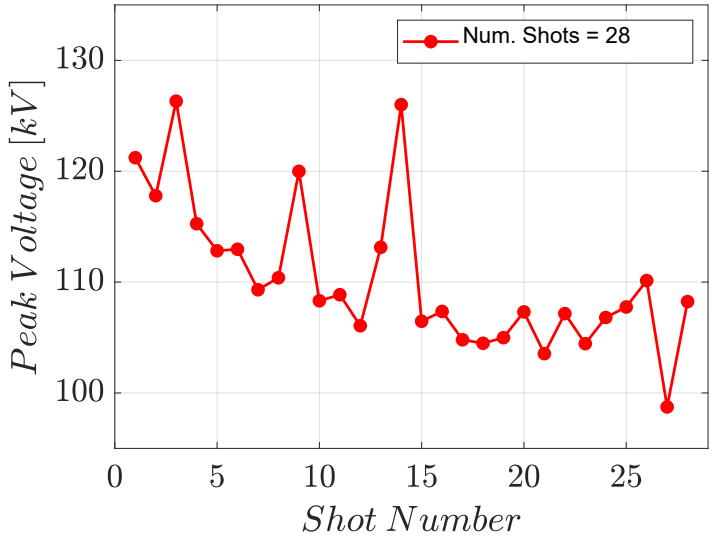
Typical Waveforms

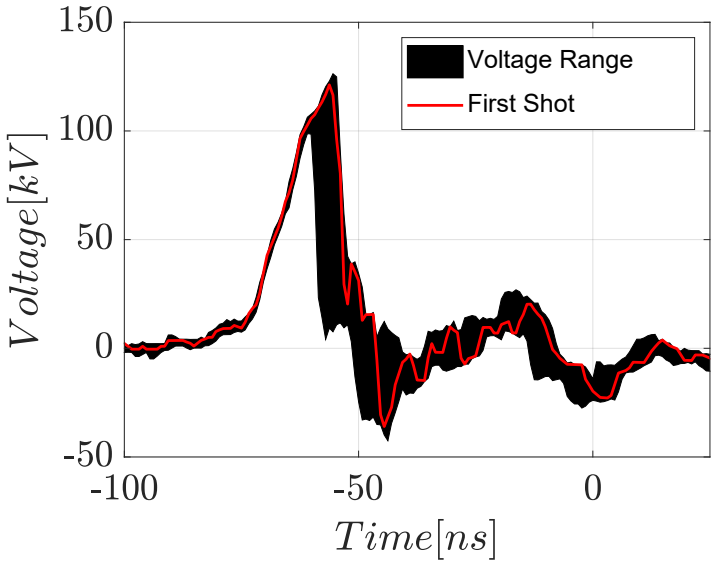
Statistics (R2.2.7.1)

- Rise Time = 13.36 ± 1.4 [ns] (std.)
- V_{peak} = 110.4 ± 6.7 [kV] (std.)
- V_{peak} Ranges (98.7 to 126.3) [kV]



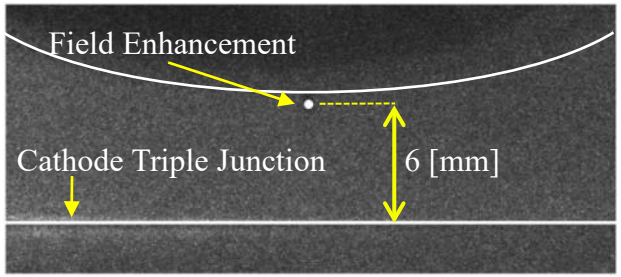
CVD: 500 mV/div, 23 dB of attenuation
CVR: 2.5 V/div, 23 dB of attenuation

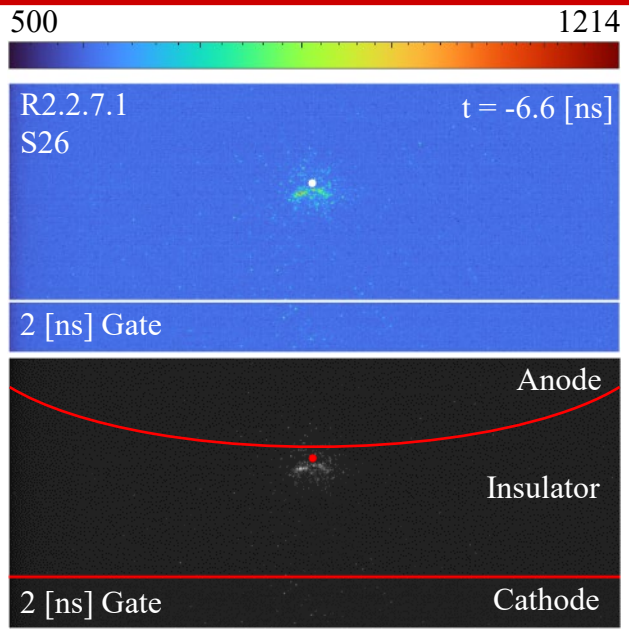


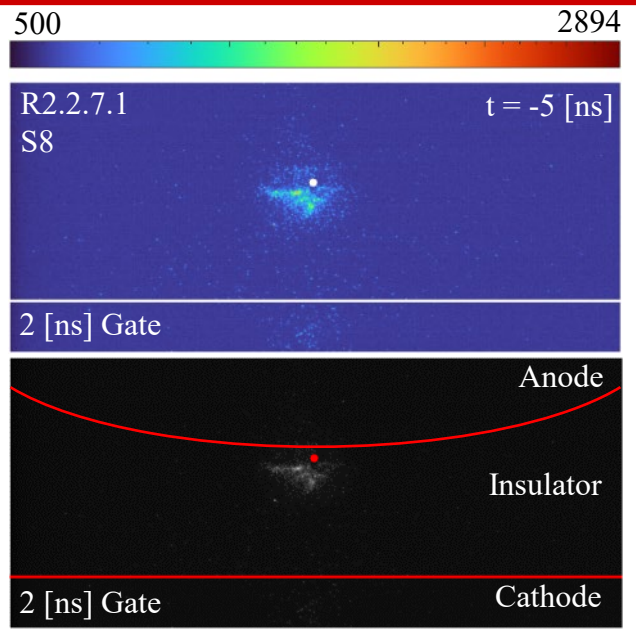


Temporally Resolved Imaging

Reference Image

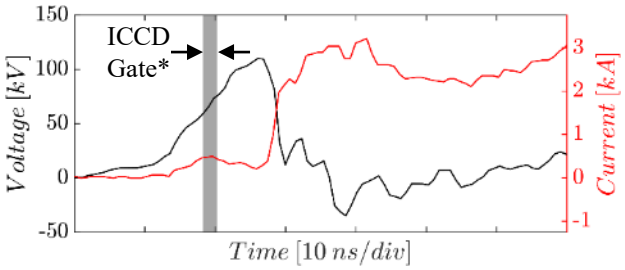


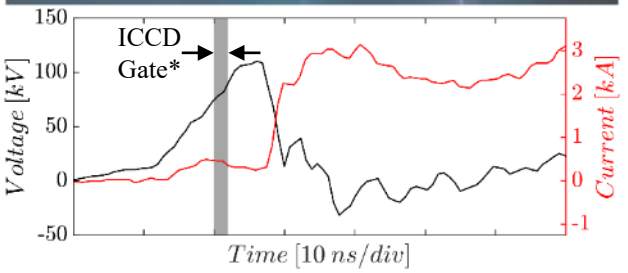




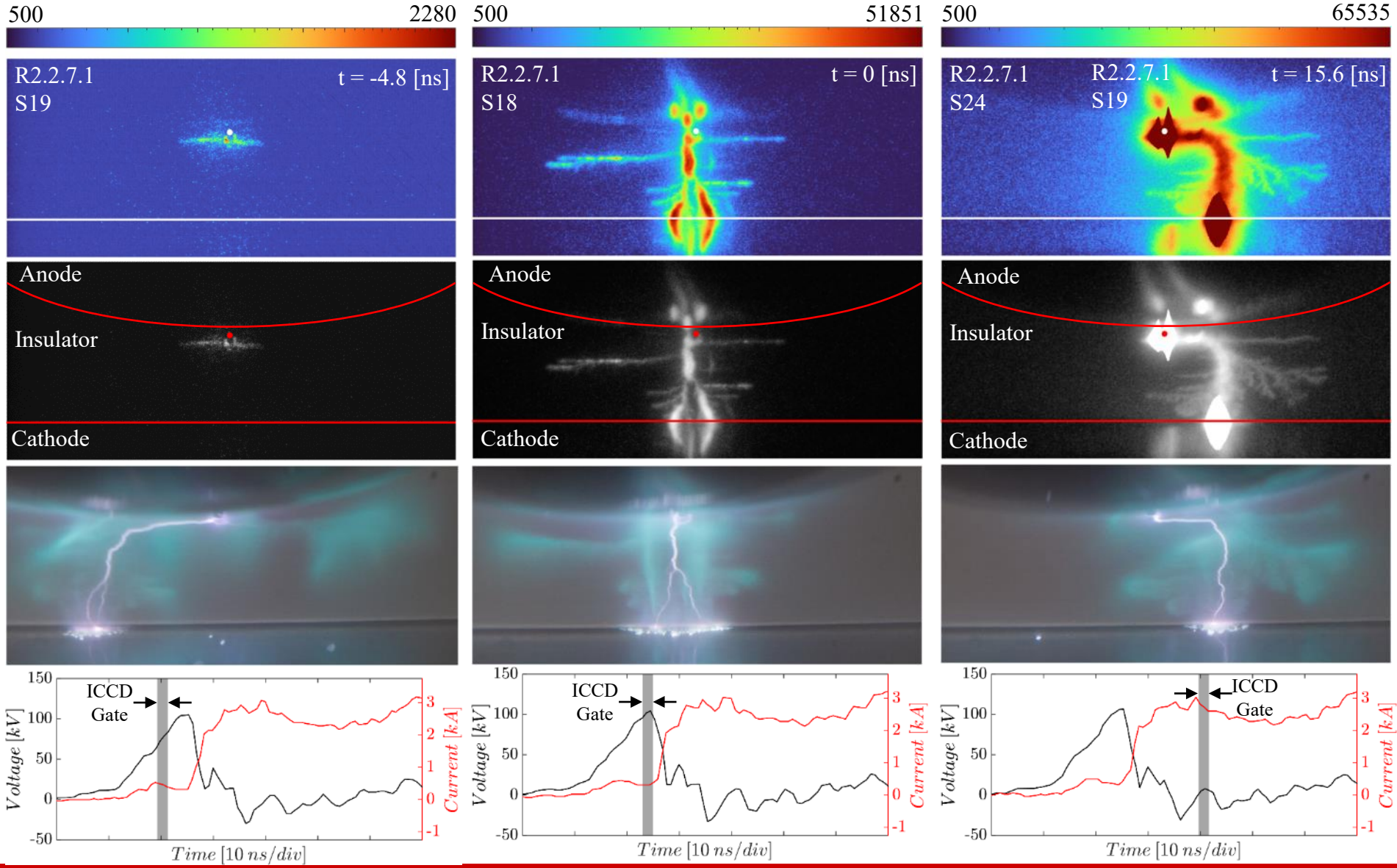
<u>ICCD Settings</u>
Gating Time: 2 [ns]
Gain: 90
F#: F/4.5

- Imaging supports anode-initiated theory
- *Small uncertainty exist in exact ICCD gating given monitor pulse is internally delayed ± 3 [ns] with respect to photocathode gating





Temporally Resolved Imaging



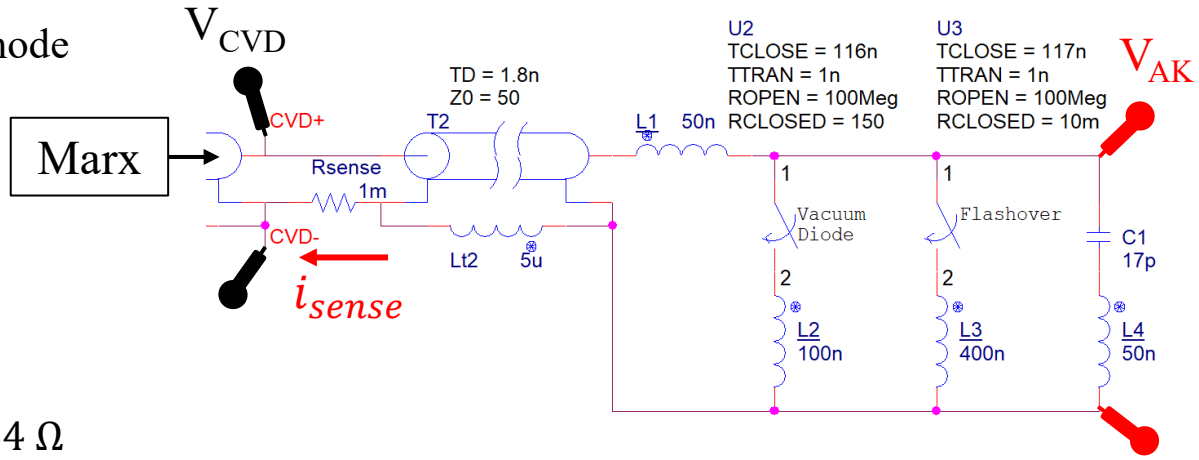
Electrical Model

Child-Langmuir diode is formed, pre-breakdown, between all anode and cathode surface area including HV feedthrough

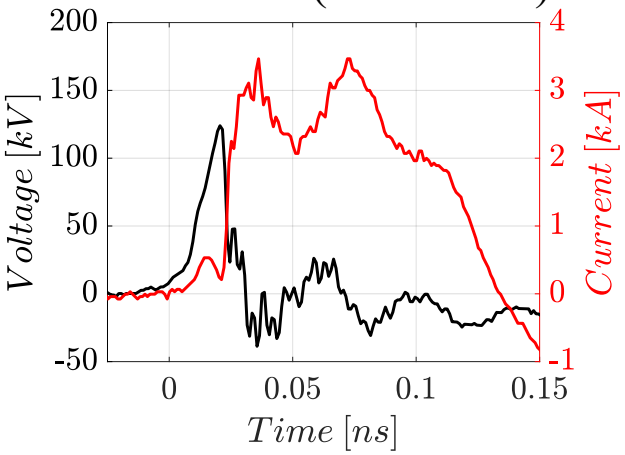
$d = 2\ [cm]$

$V_0 = 0.150\ [MV] \quad A = 27\ [cm^2]$

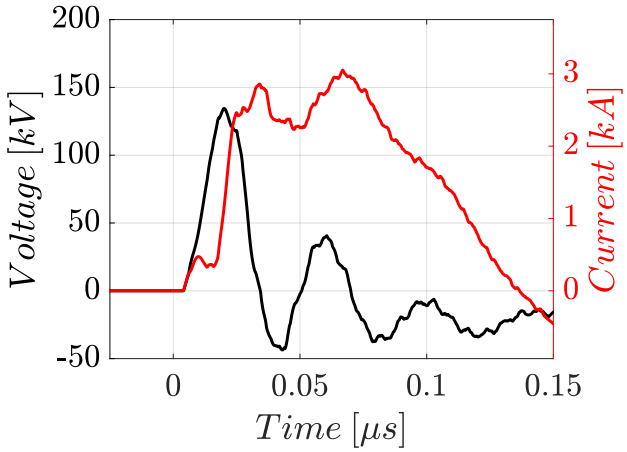
$$Z_{VD} = 429\frac{[d(cm)]^2}{A(cm^2)[V_0(MV)]^{1/2}} = 164\ \Omega$$



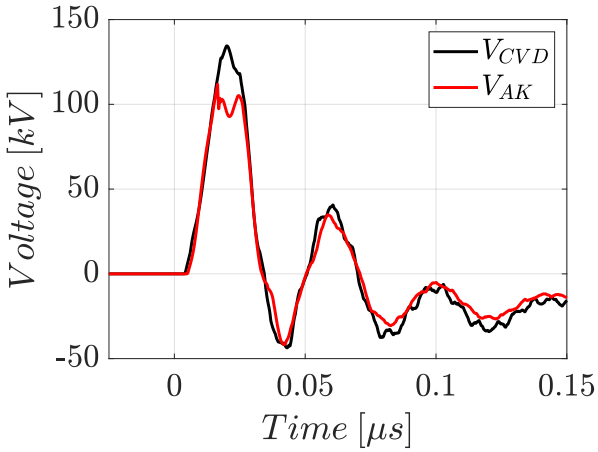
Measured (R1.9 shot1)



Simulation

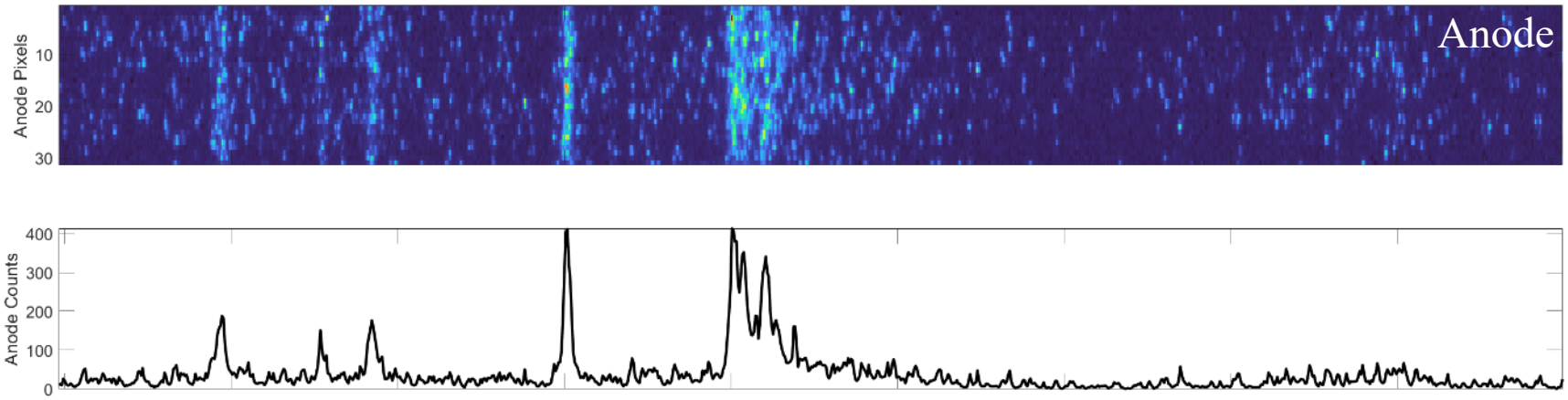


Simulation Voltage Comparison

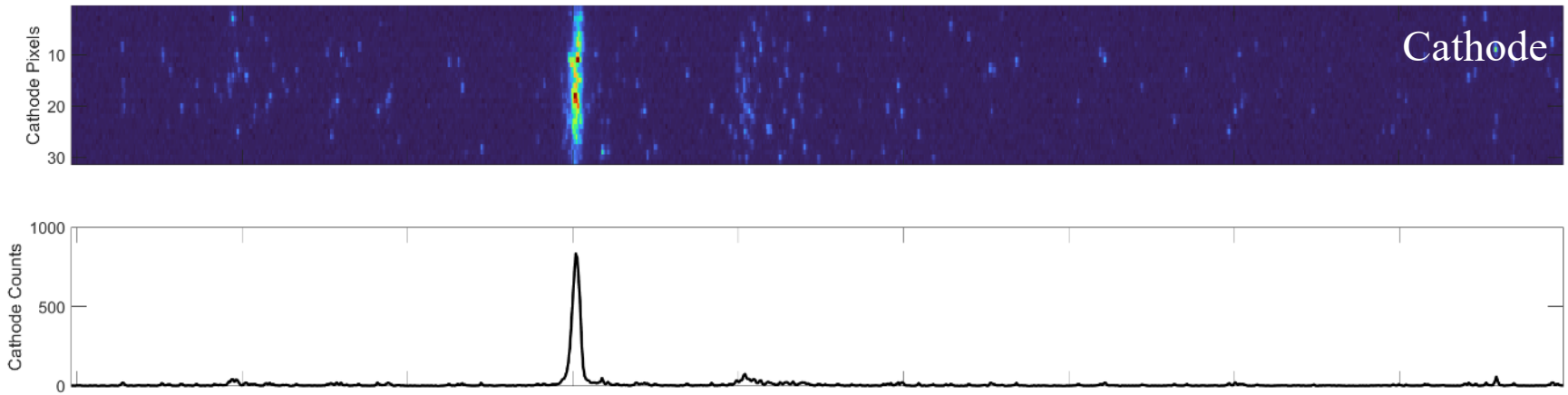


Spatially Resolved Spectroscopy

Raimi Clark, session (4O-A) on Thursday the 16th

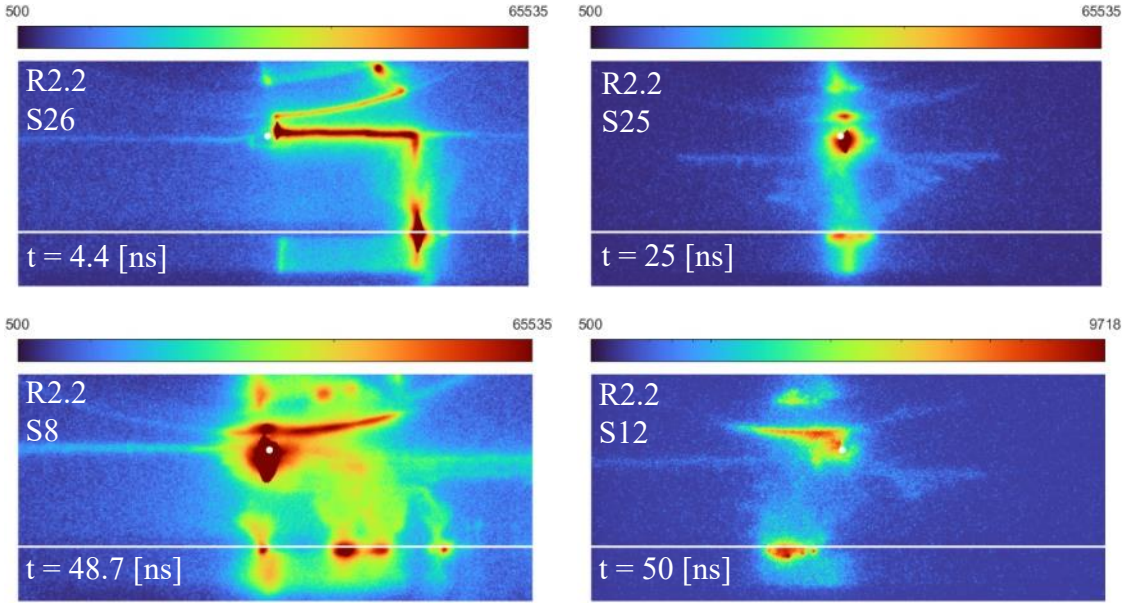


~ 465 nm center wavelength, ~ 45 nm window



Conclusions

- Conclusions:
  - Early-stage light emission originates near anode
  - Discharge develops from anode to cathode
    - Observed branching and “unsuccessful” streamer fronts
  - Emission tends to follow insulator machining defects (likely exacerbated by the specific flashover geometry)



- Future Work:
  - Develop the next generation of insulator topology to localize the flashover event to the point of interest
  - Investigate the behavior of different materials.
  - Gather additional temporally resolved images to further characterize flashover over time