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Temporally resolved light emission and optical emission spectroscopy of surface flashover in vacuum

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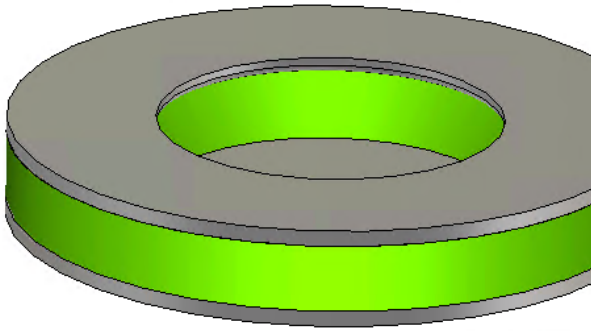
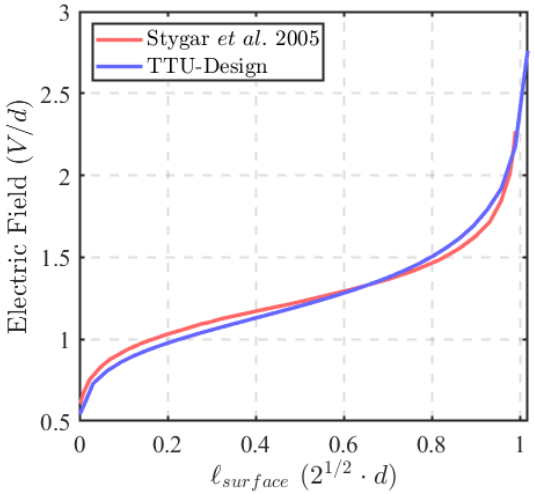
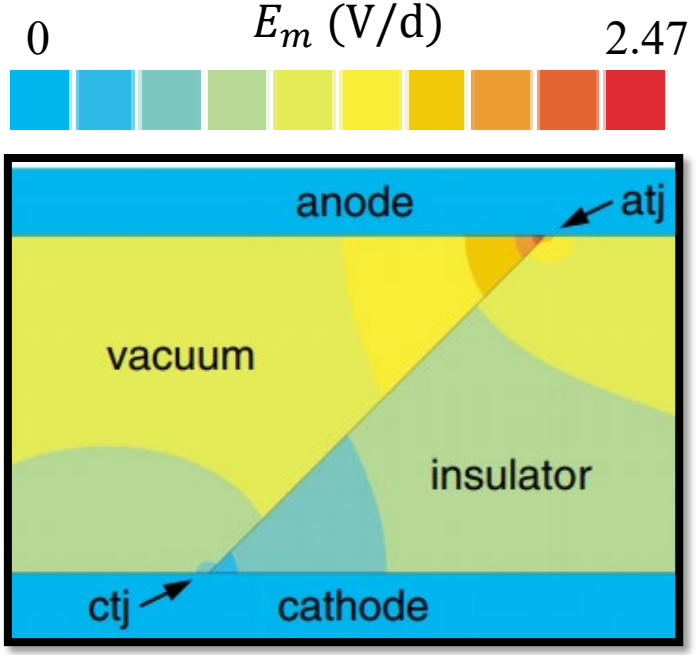
Motivation

- Determine physical mechanisms of flashover initiation in large insulator stack environments **in vacuum**
  - Improve body of evidence for anode initiated flashover
  - Identify time scales for bulk insulator involvement in flashover process
  - Support modelling efforts



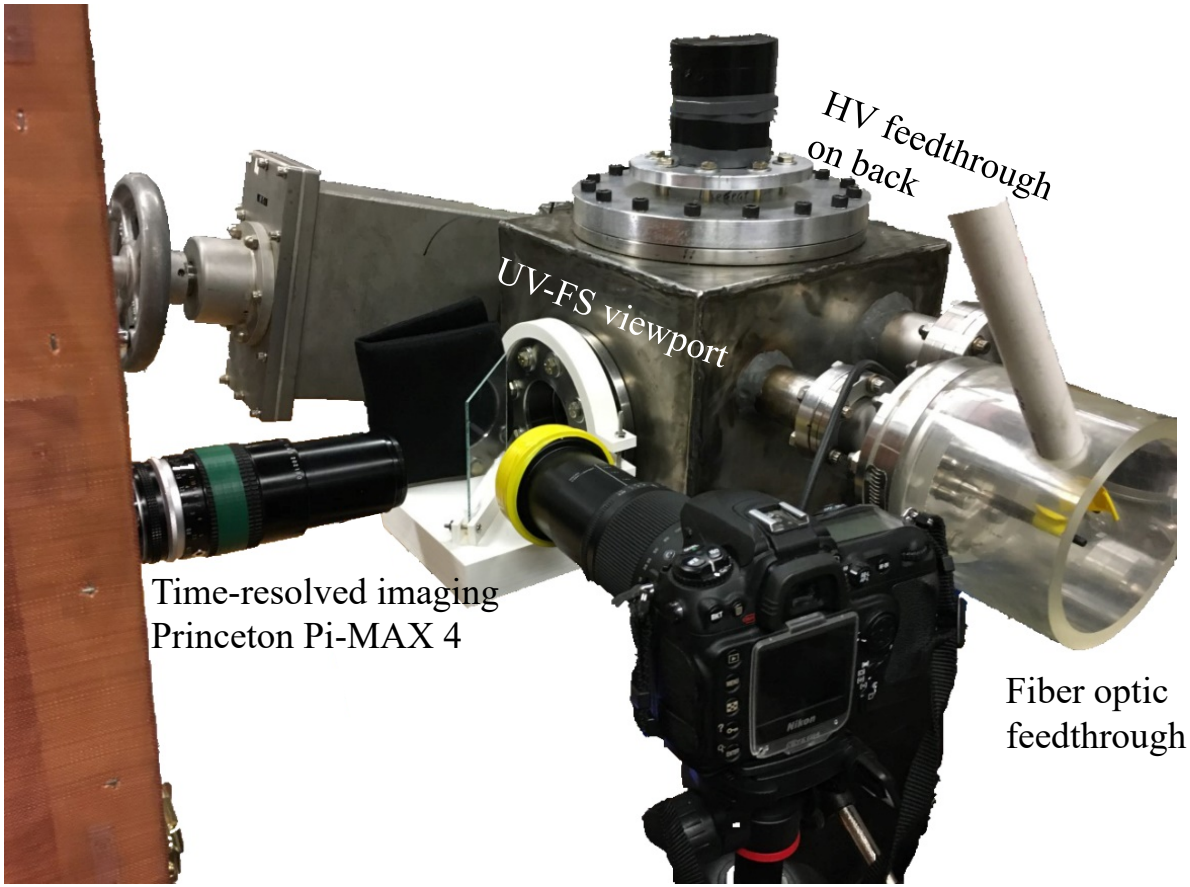
Stygar-like topology





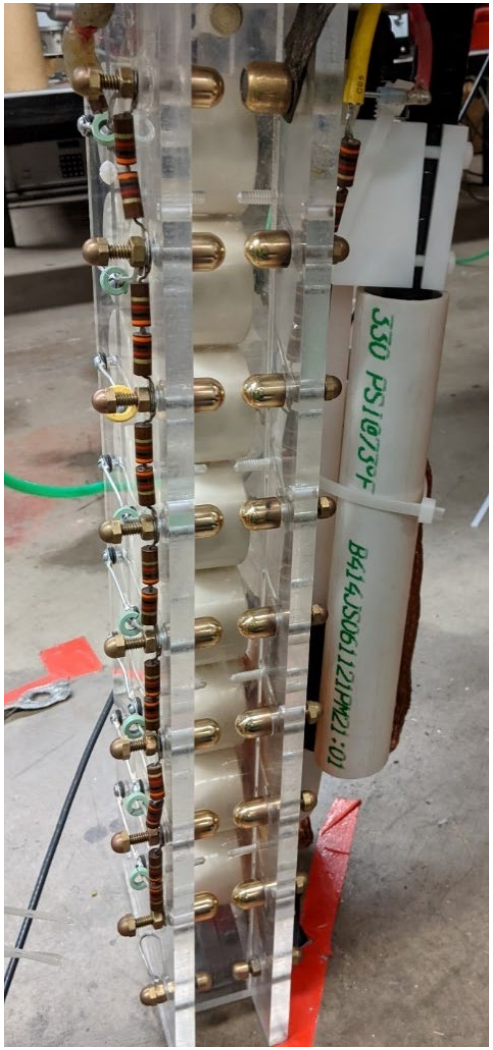
W. A. Stygar et al. 2005, Physical Review Special Topics – Accelerators and Beams 8, 050401 (2005)

Flashover Chamber and Source



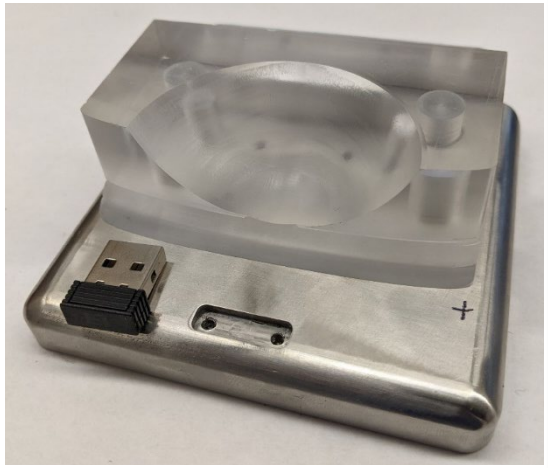
Coaxially integrated electrical diagnostics

- Capacitive voltage divider
- ~50 mΩ current viewing resistor



30 kV charged, 240 kV, 675 pF erected pressurized Marx

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

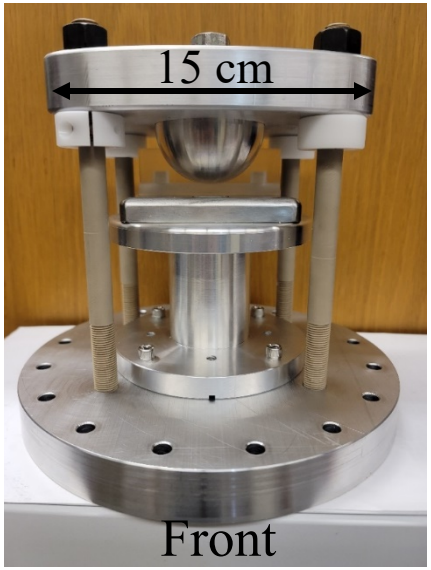
Anode

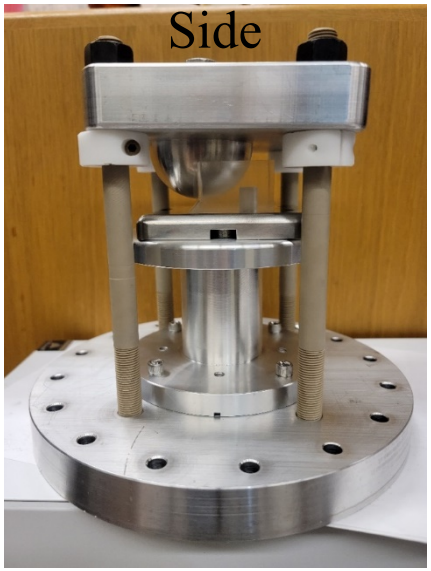
30 mm radius

Cathode

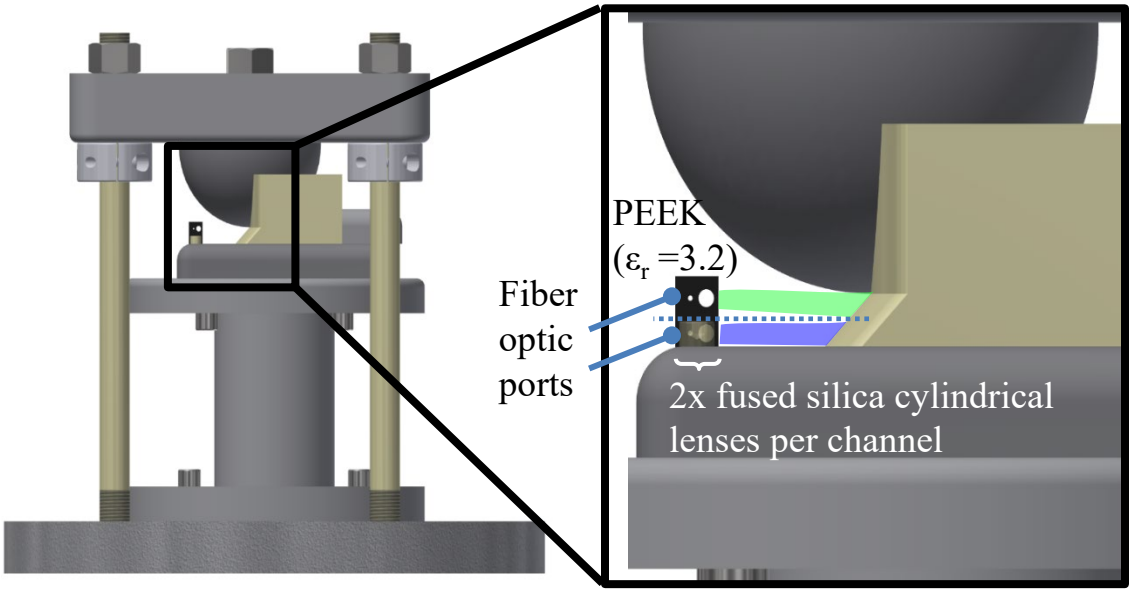
95.25 mm (3.75 in) Wide

88.90 mm (3.50 in) Deep

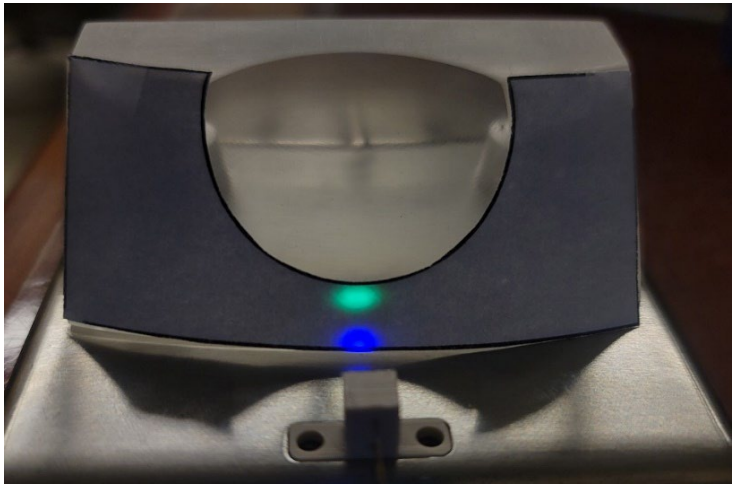




Light Collection

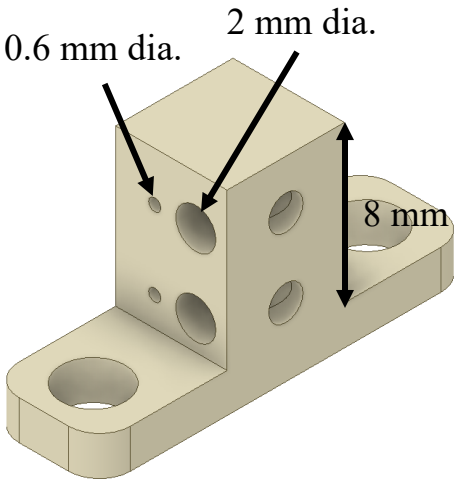


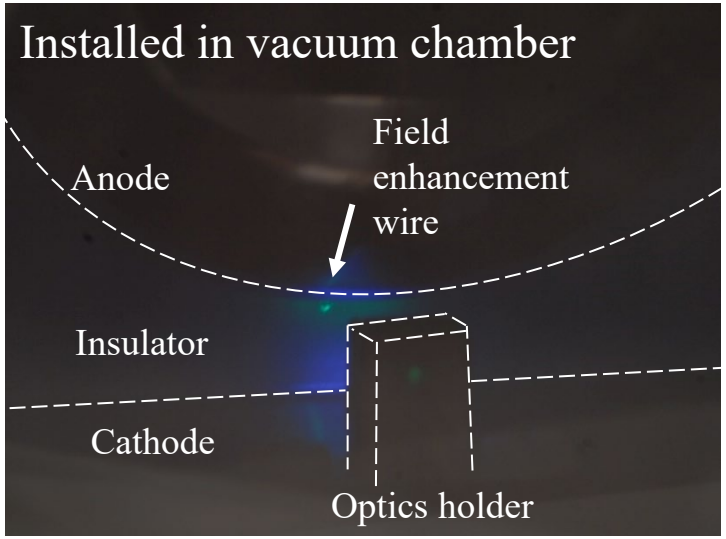
In air, projected onto paper for opacity



Multimode optical fiber
- Solarization resistant
- 180-850 nm transmission
- 200 µm core

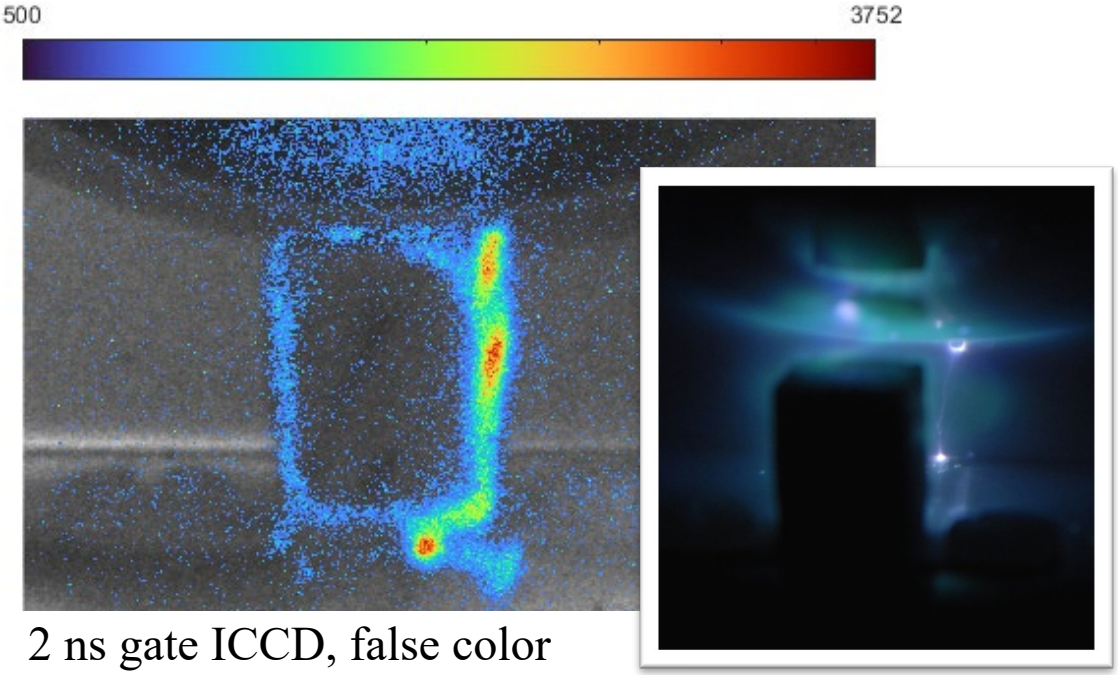
UV-FS Vacuum fiber feedthrough



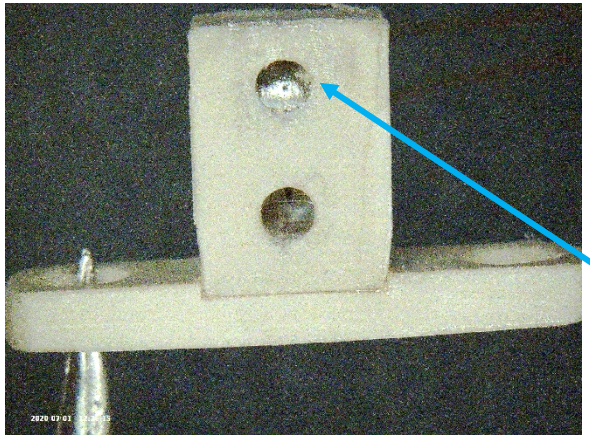


Increased diffusivity due to insulator transparency

Optics Holder Protection



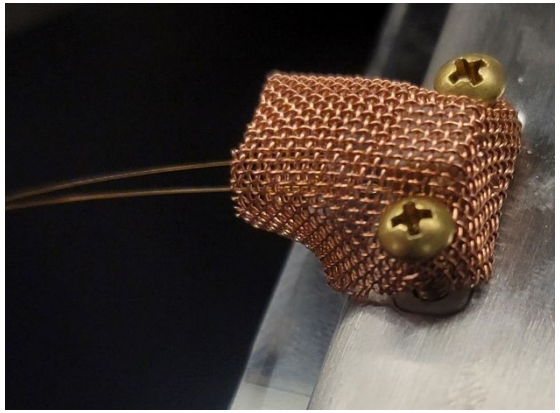
2 ns gate ICCD, false color

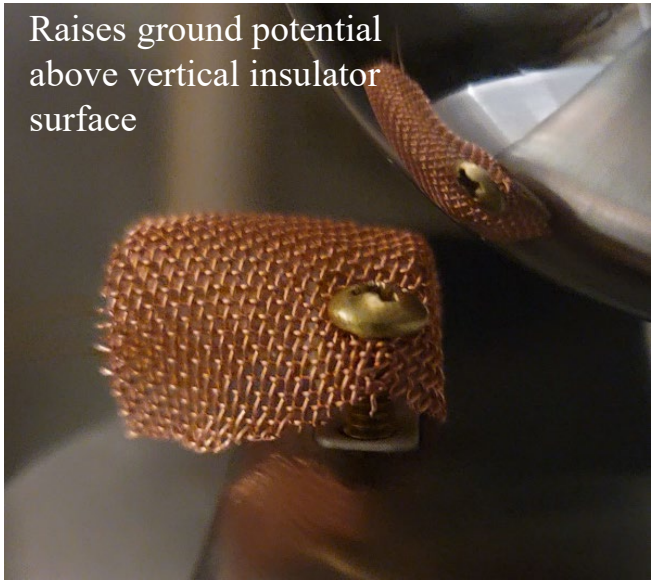


- Flashover along vertical surface of the holder
- Carbon tracking

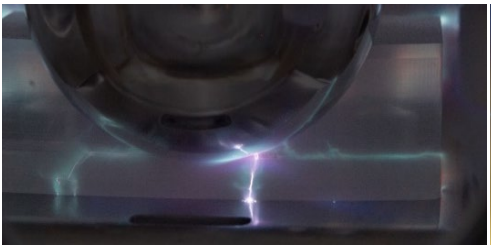
Debris from anode deposited on and around lenses

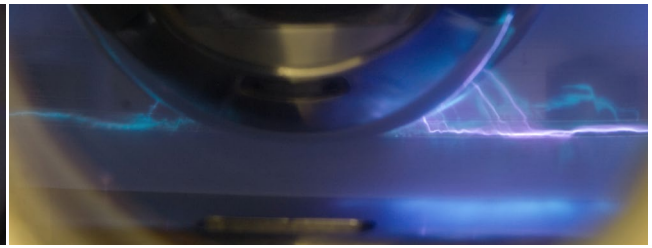
Added shield



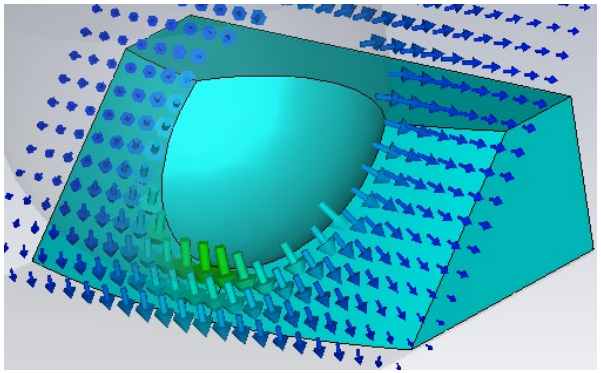


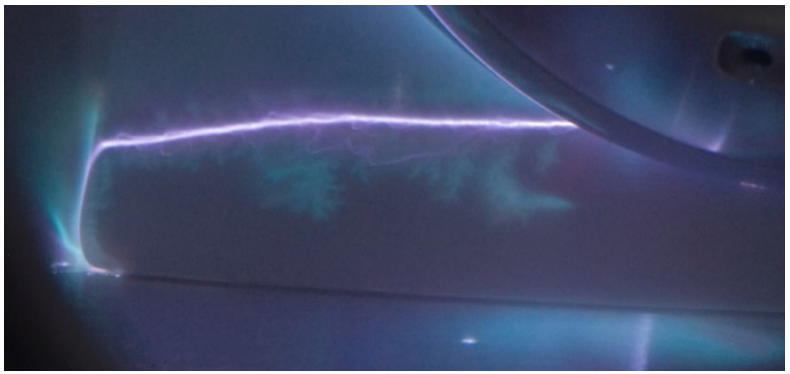
Localizing Flashover

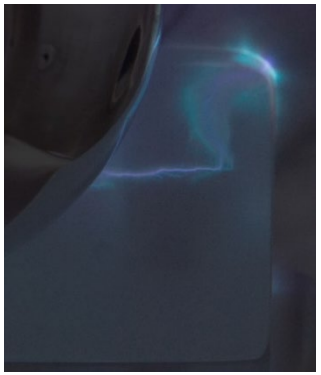




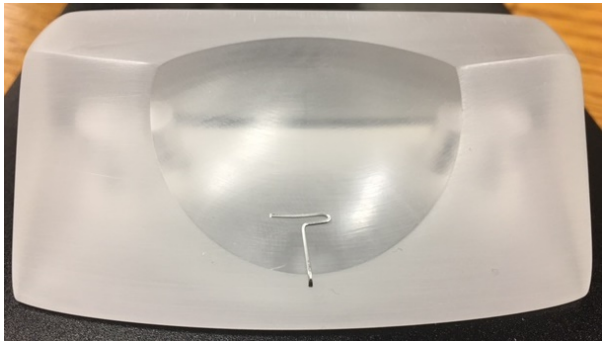
- Initial insulator geometry demonstrated inconsistent flashover locations
- Improved wedge design exhibited higher hold off, but flashover location still varied







- For reliable fiber optic diagnostics, an aluminum wire field enhancement was added to localize flashover

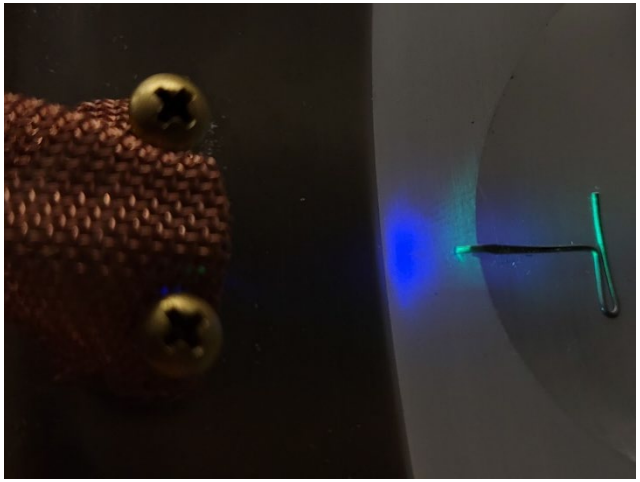


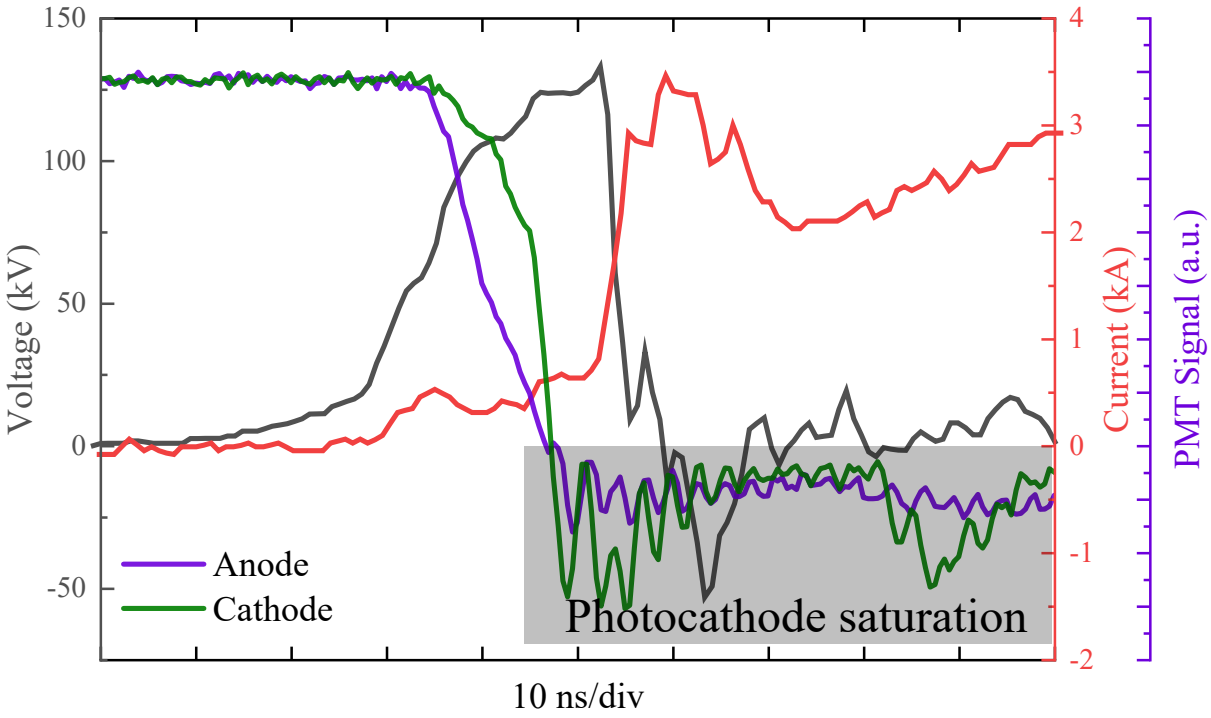
Early Light Emission

- For flashover on pristine insulator, first light appears at anode
- Voltage, current, and intensity waveforms timed to within ± 1 ns

Early light detection with Thorlabs PMTSS

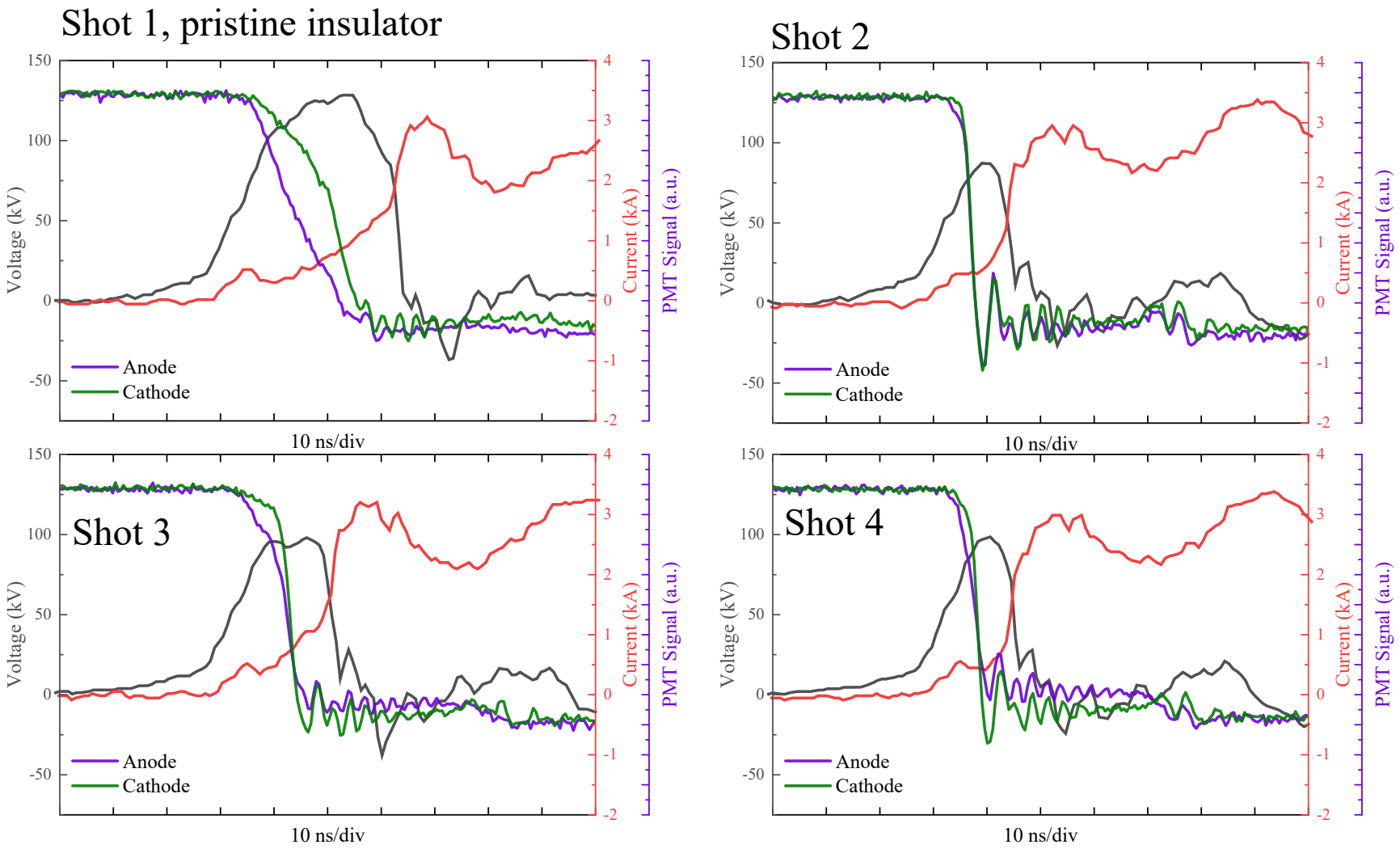
- 1.4 ns rise time
- 185-900 nm spectral response
- Gain > 10^7



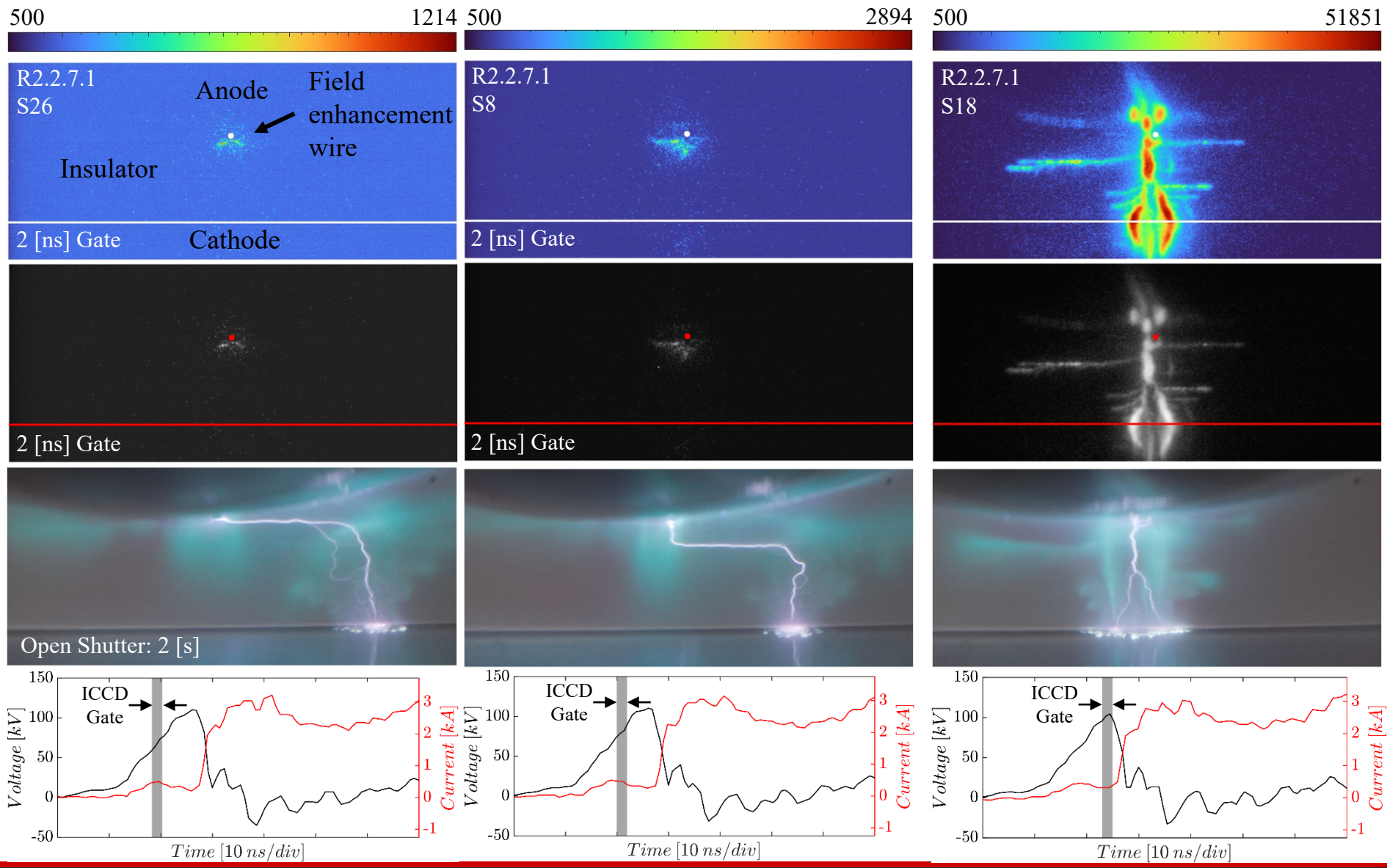


Light Emission Sequence

- Time lag for cathode light becomes less pronounced after repeated shots

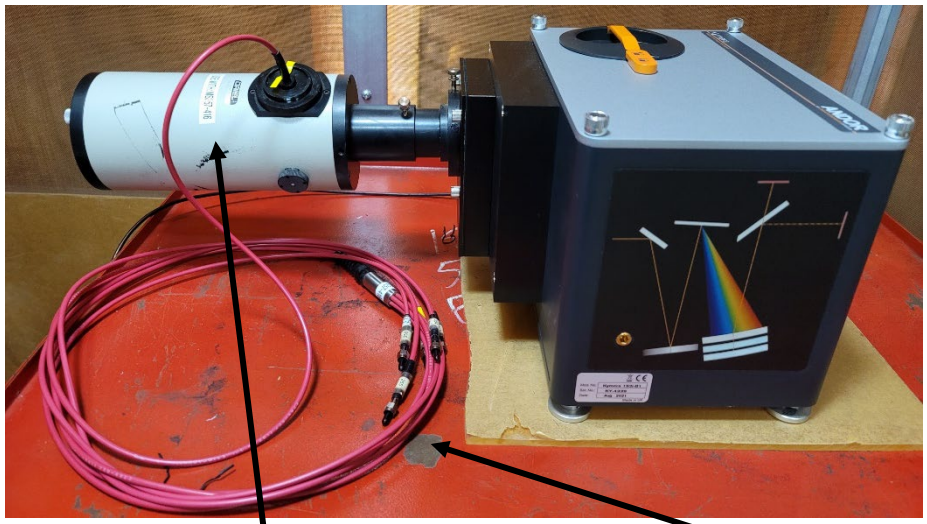


Time Resolved Imaging



Spatially Resolved Spectroscopy

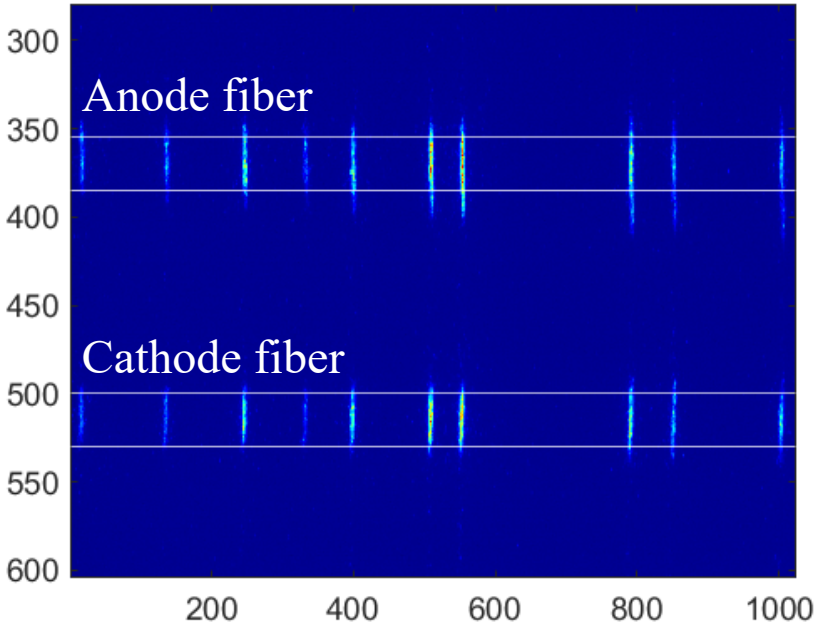
- Andor Kymera 193i Spectrograph
  - 1200 g/mm
  - 500 nm blaze
- Princeton Pi-MAX 4 ICCD
  - Sub-ns gate capable



Fiber collimating element

Fiber optic bundle
- 260-1000 nm

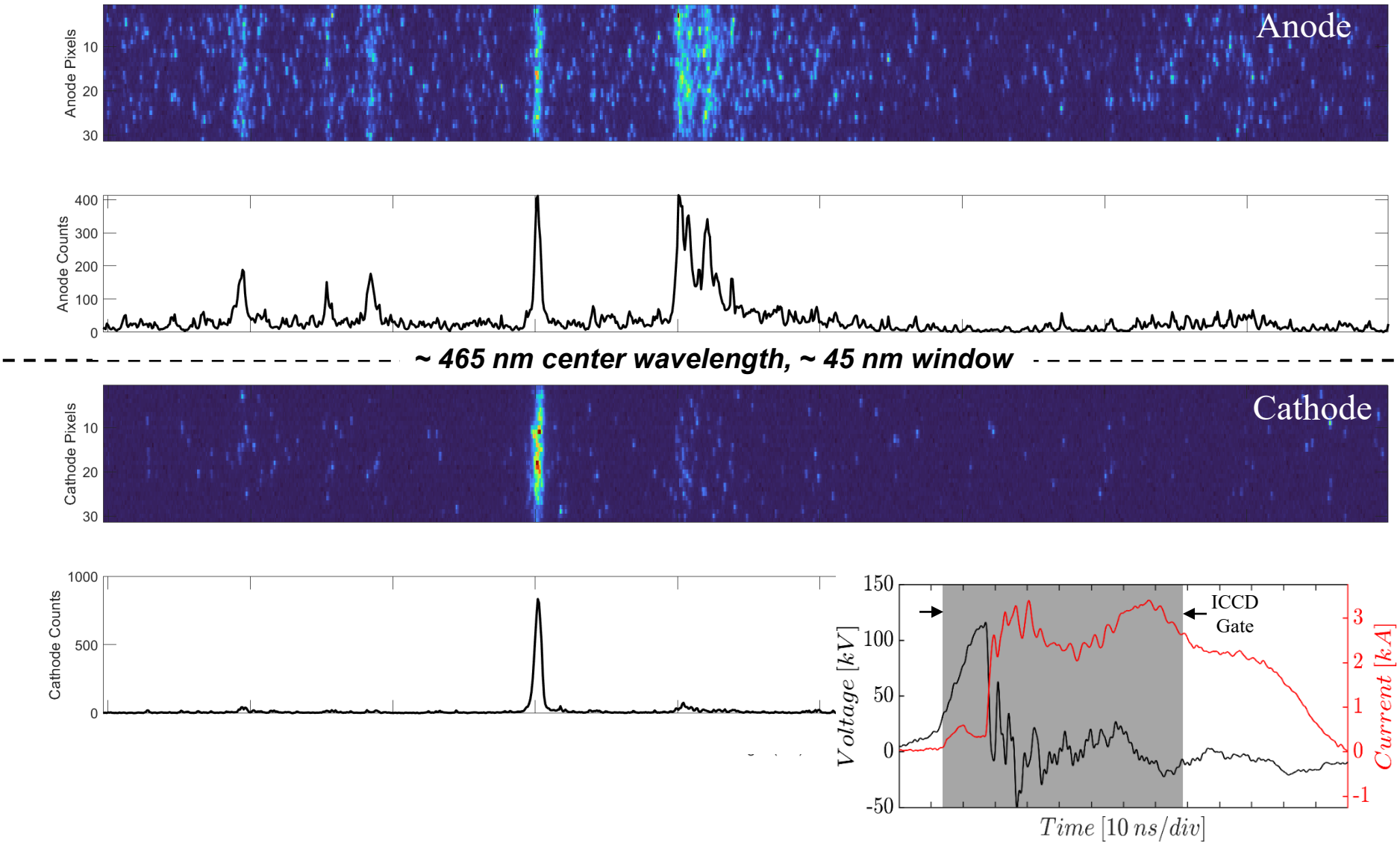
Neon CW source fed into fibers to demonstrate spatial resolution on ICCD



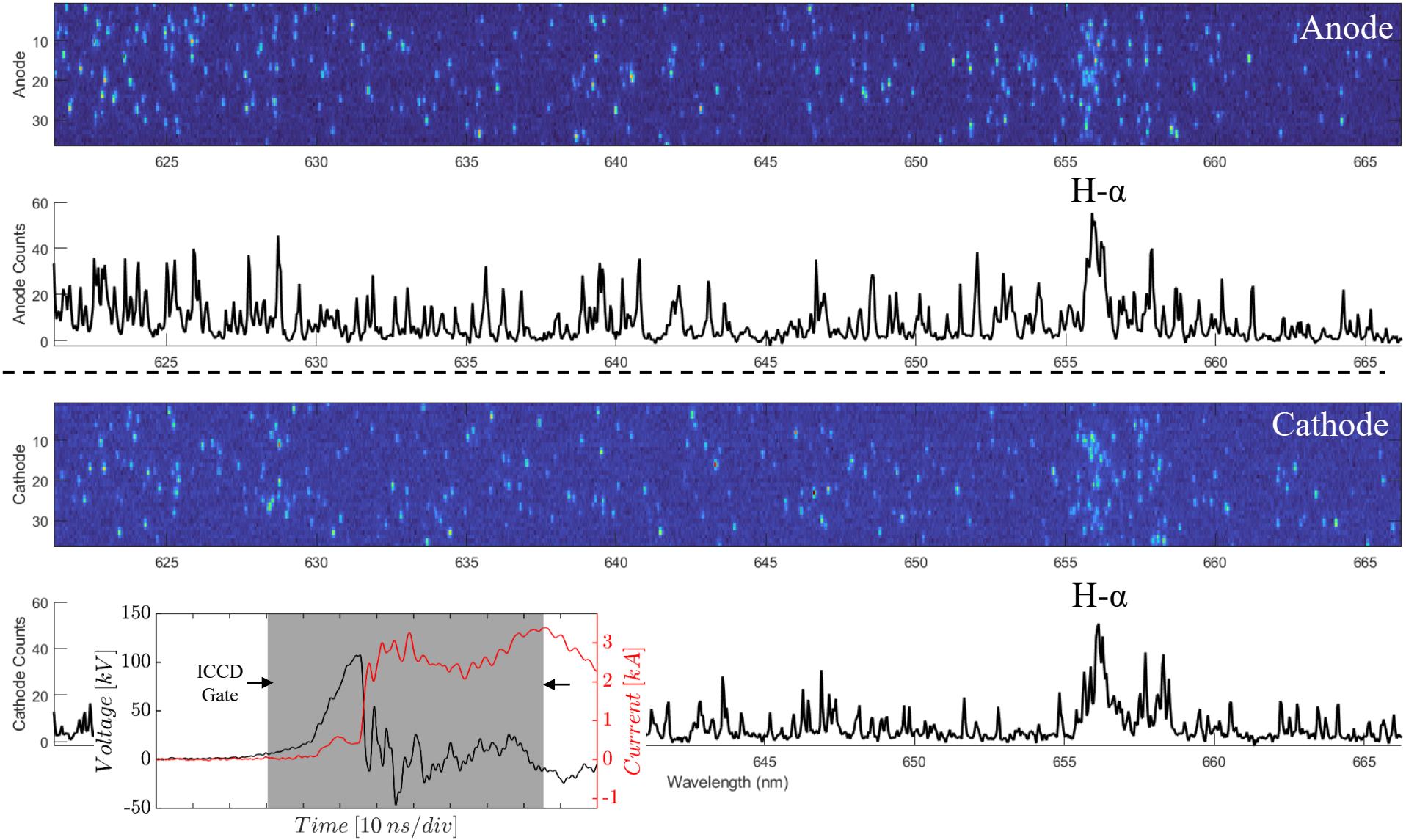
- Vertical binning over 31 pixels
- Separation between bins > 100 pixels

- Upcoming spectra recorded with 50 µm slit

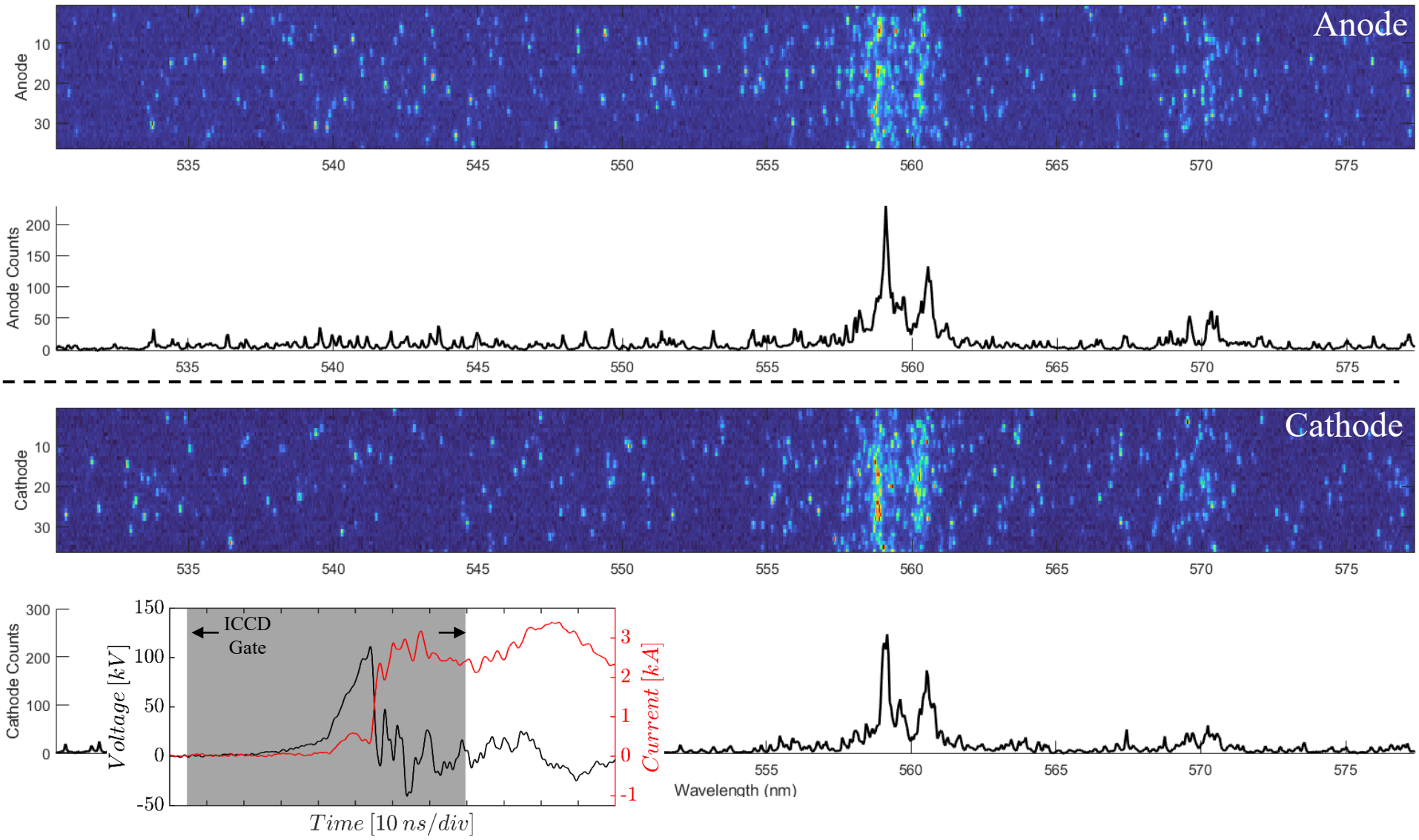
OES Example


Anode
Anode Pixels
10
20
30
Anode Counts
400
300
200
100
0
~ 465 nm center wavelength, ~ 45 nm window
Cathode
Cathode Pixels
10
20
30
Cathode Counts
1000
500
0
150
100
50
0
-50
Voltage [kV]
ICCD
Gate
3
2
1
0
-1
Current [kA]
Time [10 ns/div]

OES Example


Anode
Anode
10
20
30
625
630
635
640
645
650
655
660
665
H-α
Anode Counts
60
40
20
0
Cathode
Cathode
Cathode Counts
ICCD
Gate
Voltage [kV]
Current [kA]
Time [10 ns/div]
150
100
50
0
-50
3
2
1
0
-1
Wavelength (nm)

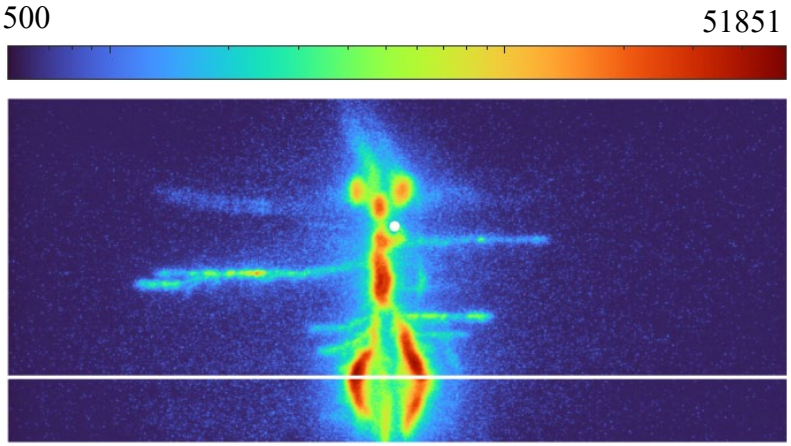
OES Example


Anode
Anode
10
20
30
535
540
545
550
555
560
565
570
575
Anode Counts
200
150
100
50
0
Cathode
Cathode
Cathode Counts
300
200
100
0
150
100
50
0
-50
ICCD
Gate
Voltage [kV]
Current [kA]
3
2
1
0
-1
Time [10 ns/div]
Wavelength (nm)

Conclusions

Conclusions:

- Successfully implemented spatially resolved photodetection across insulator surface
- Early light supports anode-initiated flashover
- Suspected detection of carbon spectra near anode may indicate bulk involvement



Future Work:

- Improve fiber coupling to spectrograph to access wavelengths <260 nm
- Time-resolved (early) spectra to identify progression of breakdown into bulk insulator
- Continued development of insulator geometry
  - Localize the breakdown **without** the need for the wire