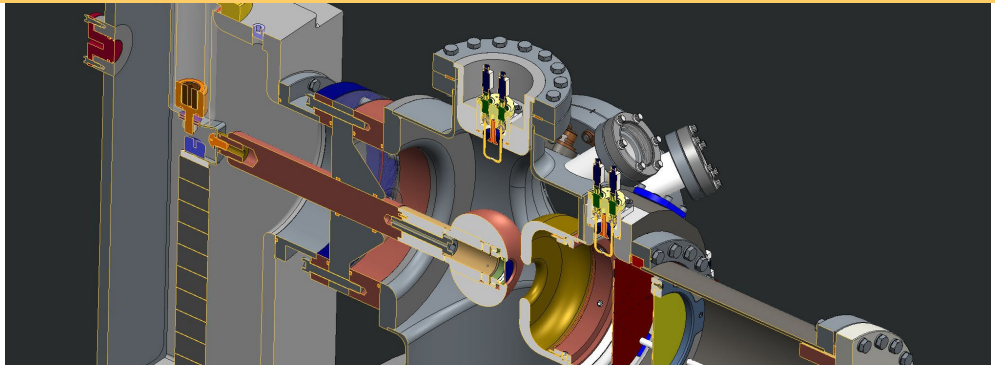
A long pulse test stand for field emission cathodes and photocathodes



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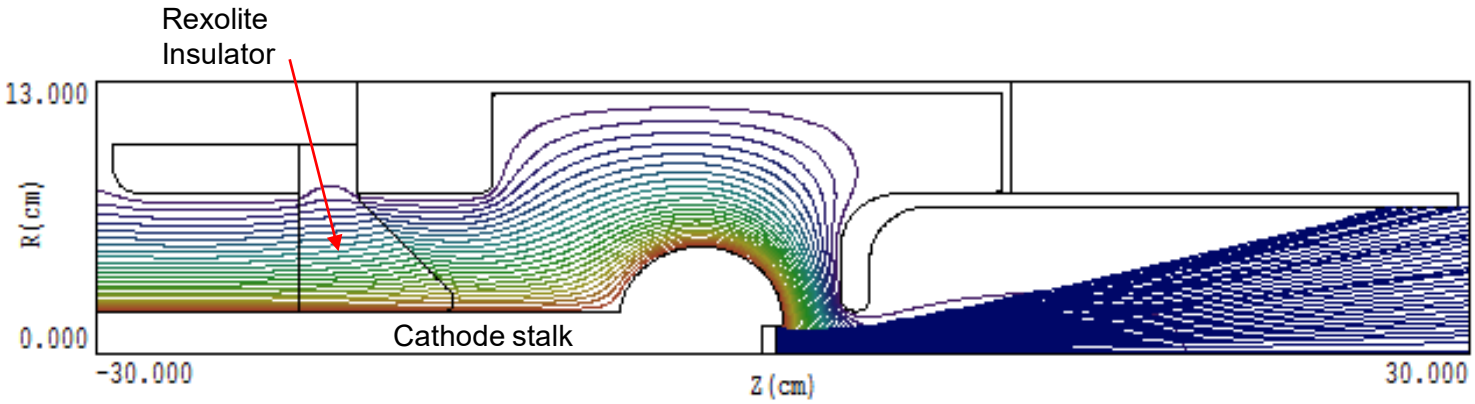
Outline

- **Diode design**
- **Mechanical design, diagnostics**
- **Commissioning**
- **25 mm cathode results**
- **Scanning electron microscope cathode measurements**
- **15 mm cathode results**
- **TRAK fits to the data**

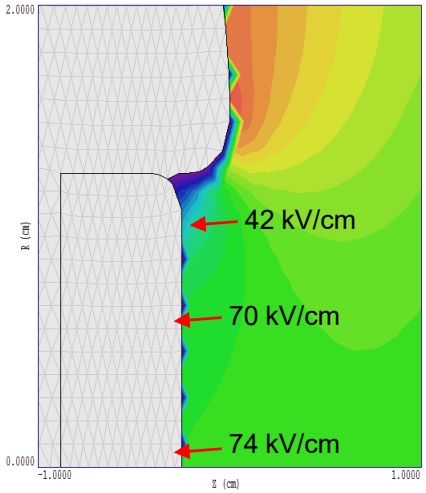
Motivation: High brightness sources

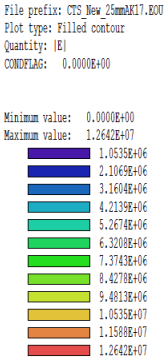
- Radiography: 1-2 kA, 100 ns, >100 uC/bunch, ε < 500 mm mrad
- Light sources: 1 kA, 1 ps, >100 pC/bunch, ε < 1 mm mrad

The diode was designed in 2013 to withstand moderate field stresses on long time scales.



250 kV on diode,
151 A extracted





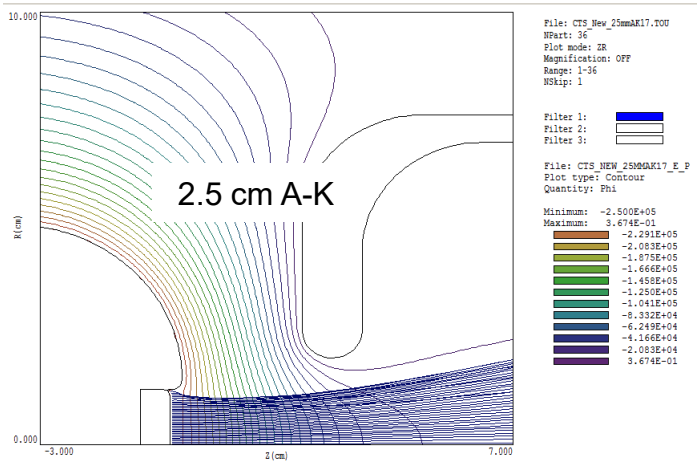
250 kV on diode

Current for last 5 runs

16	151.24
17	151.20
18	151.19
19	151.20
20	151.19

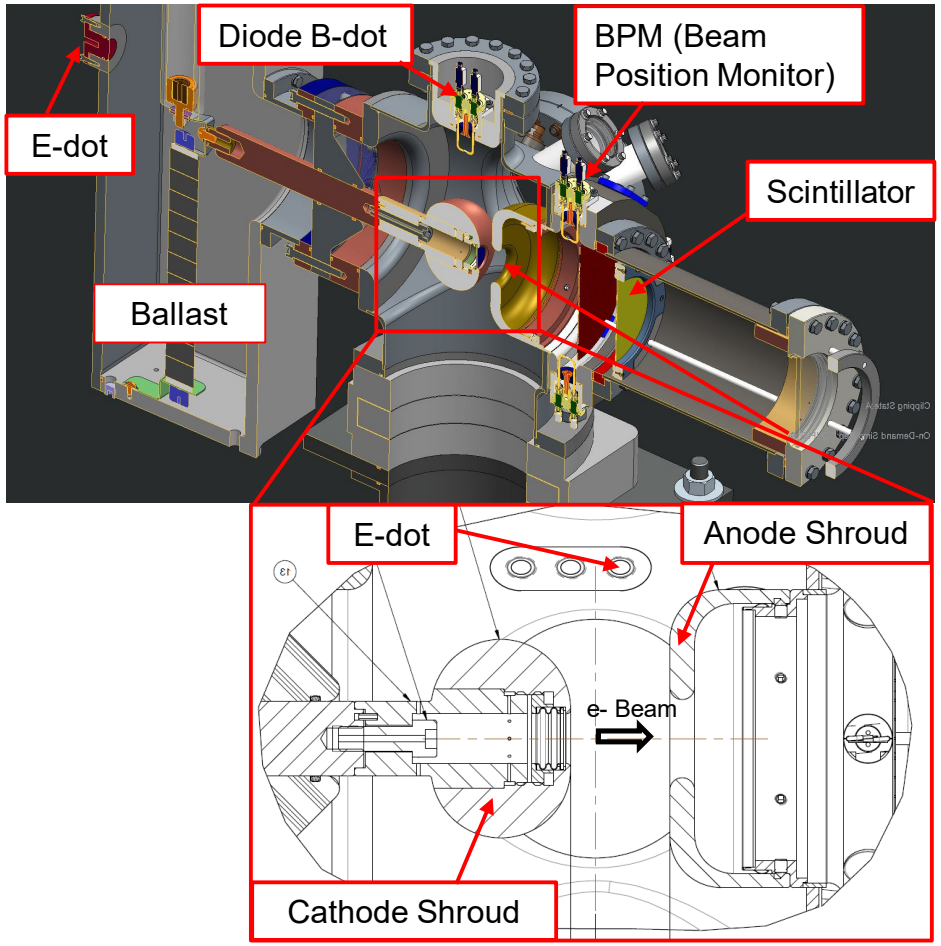
File: CTS_New_25mmAK17.TIN
File: CTS_New_25mmAK17.TLS
8 sec run

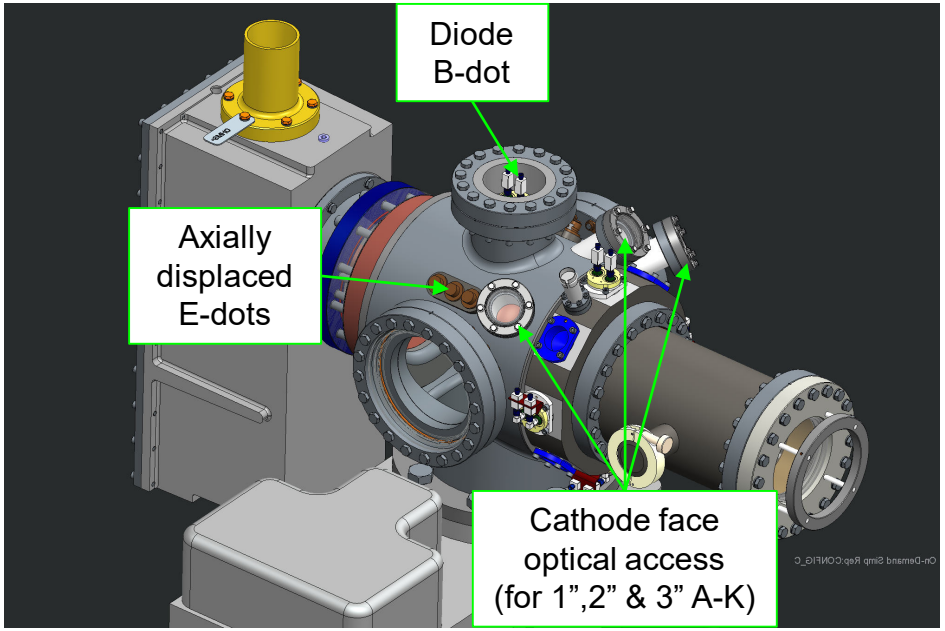
A-K: 2.5 cm
Aperture: 2 cm



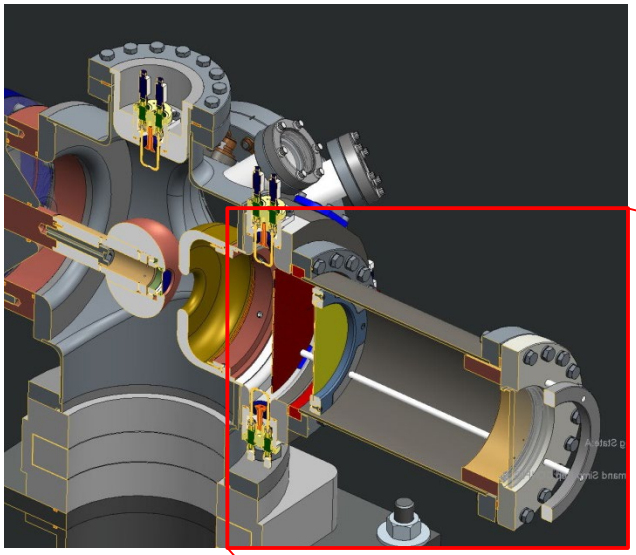
Peak E-field on shroud is 120 kV/cm (12 MV/m)

The mechanical design was completed in 2014 and fabrication was completed in 2015.

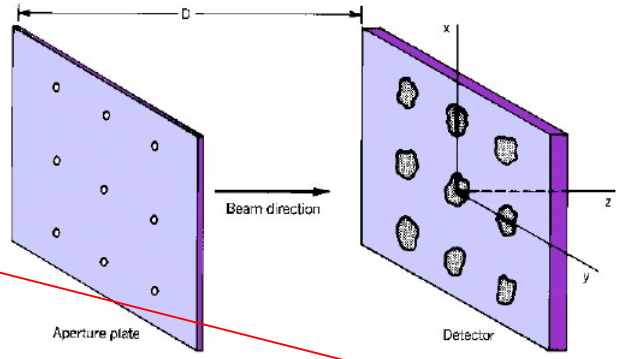




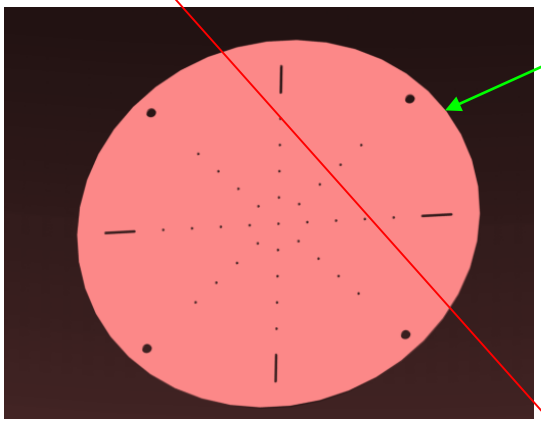
Optical diagnostics for measuring J and ε.



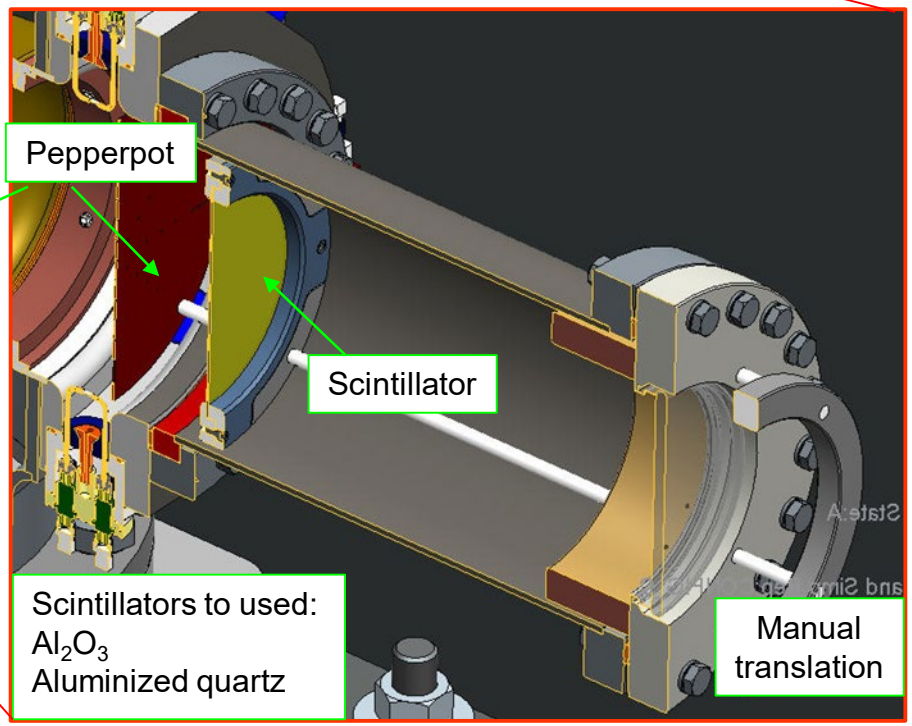
Beamlets must be emittance dominated



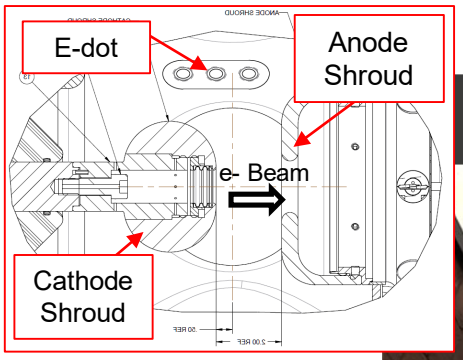
Pepperpot – emittance diagnostic

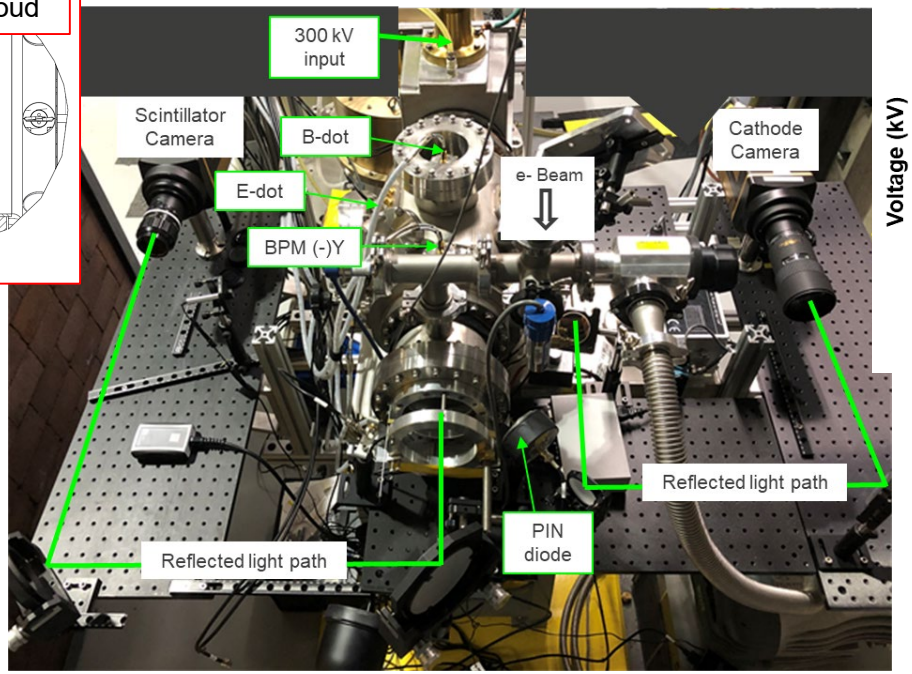


Optical diagnostic details

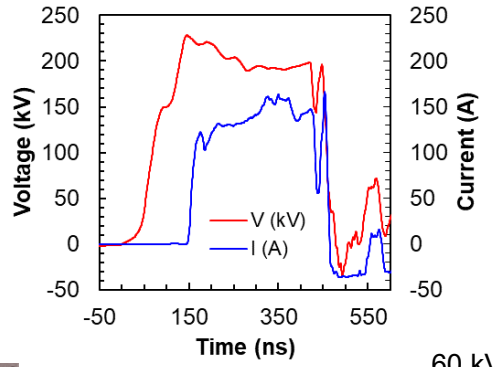


Pulsed power testing, radiation enclosure certification, and other commitments delayed commissioning until 2020.



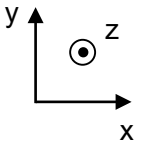


Diode extraction voltage and measured current

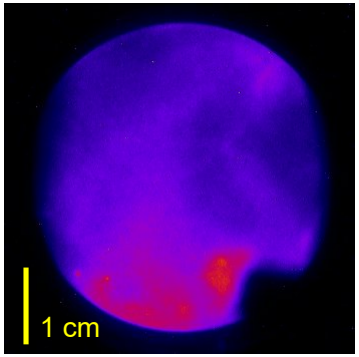


Shot 5807

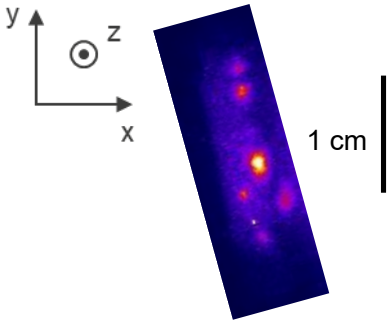
60 kV charge

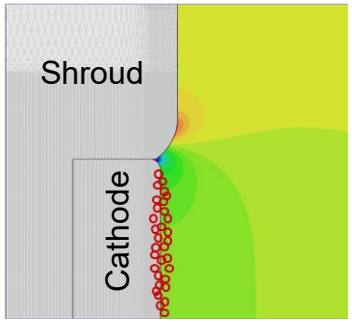


Scintillator image



Cathode image





Emission observed at ~40 kV/cm

Process

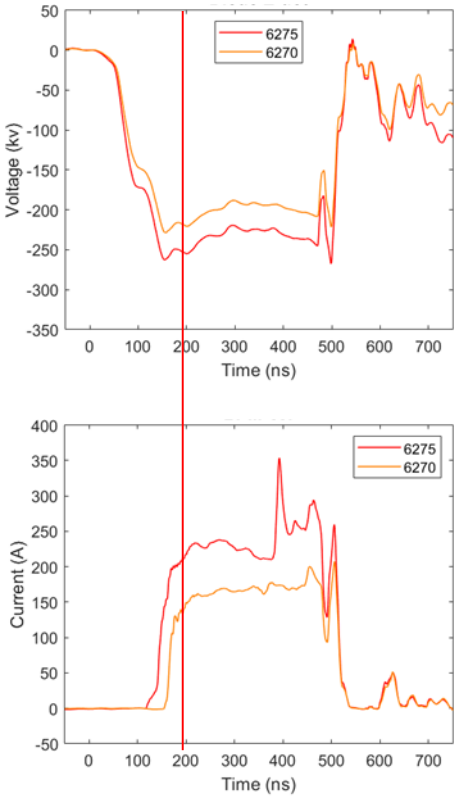
(1) Strong E-field > 10 kV/cm drives primary electrons off the surface

(2) These electrons desorb and ionize the monolayers of gas on the velvet surface

(3) Avalanche of electrons is accelerated

Field emission
Ionization
Acceleration

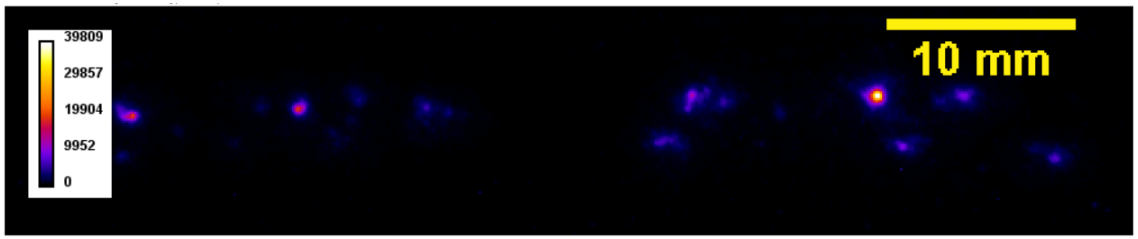
Field emission was limited to higher voltage operations despite reliable ~400 ns pulse operation with a 25 mm cathode.



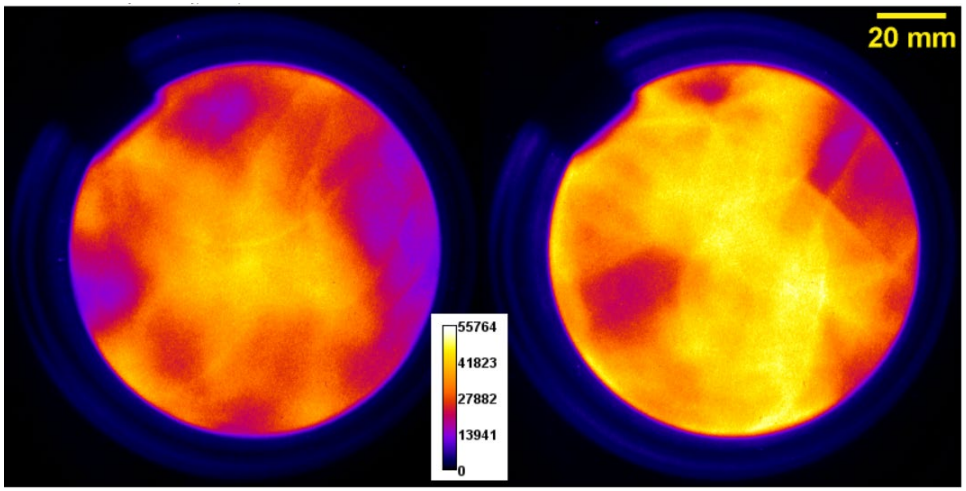
Rise time	Max voltage
86 ns	230 kV
88 ns	263 kV

200-400 ns
<V> = 197 +/- 10 kV
<V> = 230 +/- 6 kV

Cathode emission



J(x,y), z = 14.3 cm

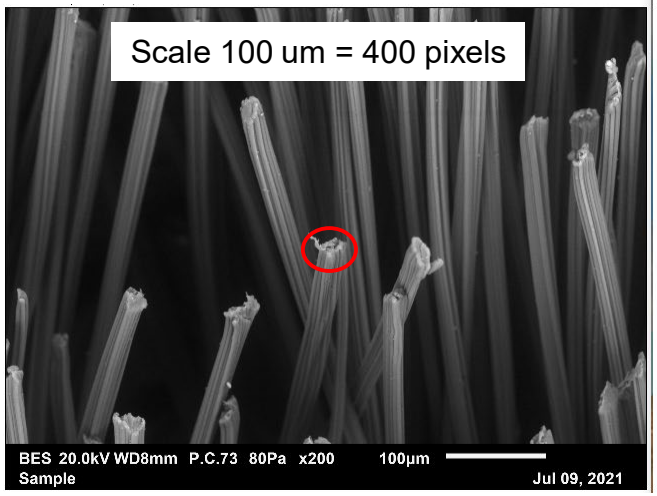


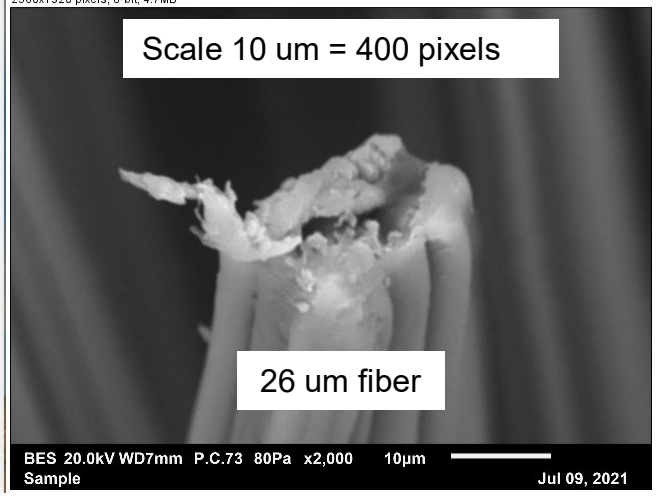
Shot 6270 6275

Poor cathode imaging setup improved for future measurements

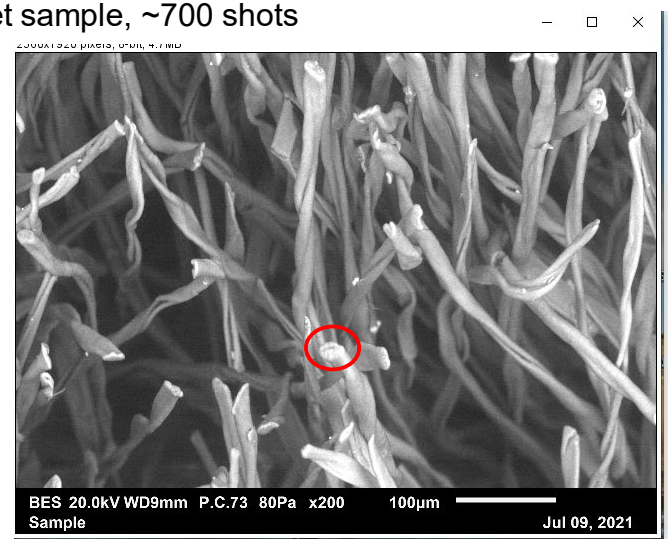
SEM measurements of velvet cathode material.

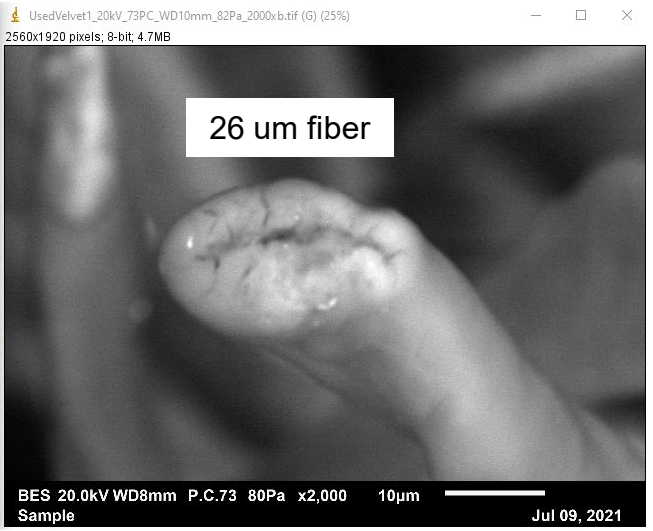
Fresh velvet sample





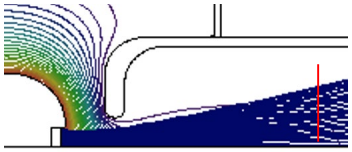
Used velvet sample, ~700 shots

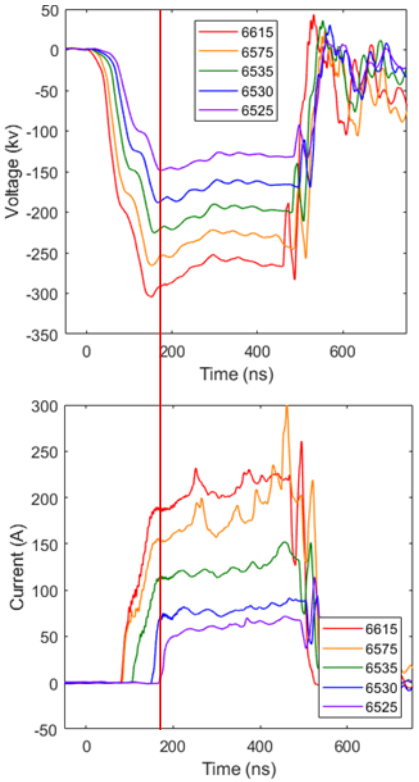




Used sample indicates blunting of the tips: field erosion

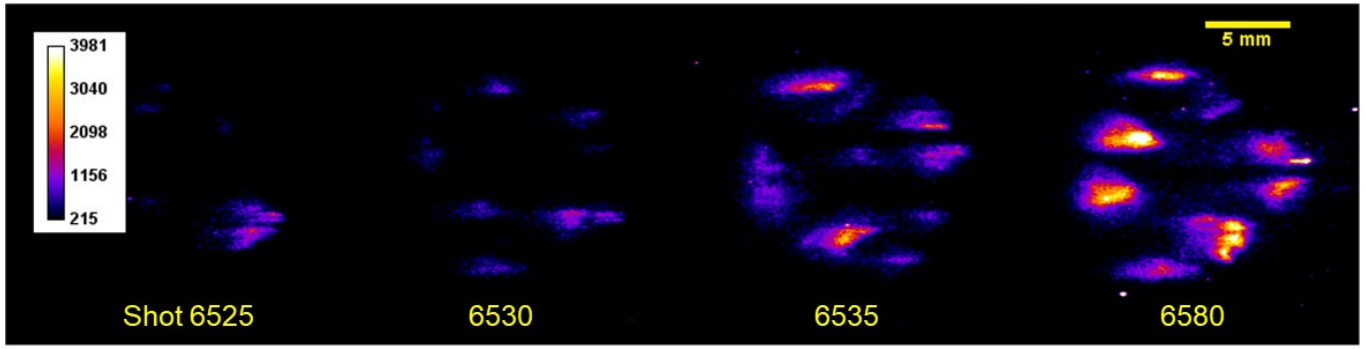
We have demonstrated reliable ~400 ns pulse operation at several voltages with a 15 mm cathode.



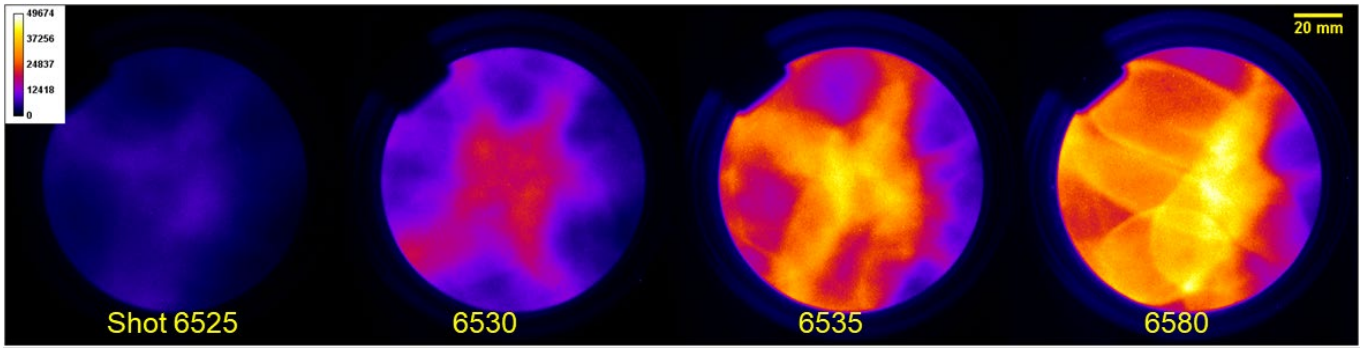


This data indicates emission initiates at E > 40 kV/cm

Cathode emission



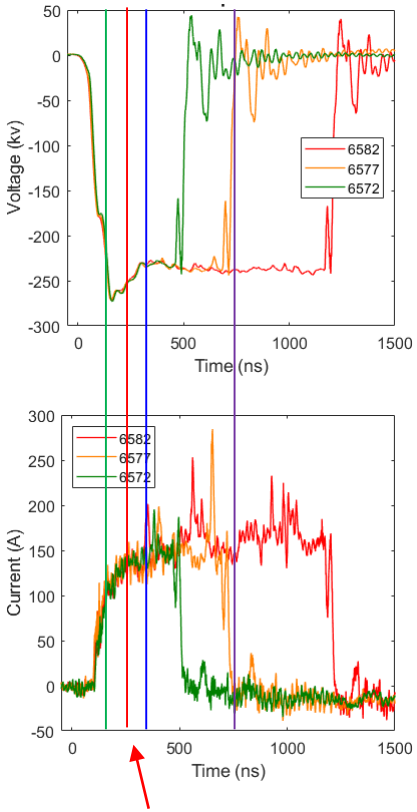
J(x,y), z = 14.3 cm



V,I = 147 kV, 51 A | 187 kV, 77 A | 219 kV, 119A | 250 kV, 164 A

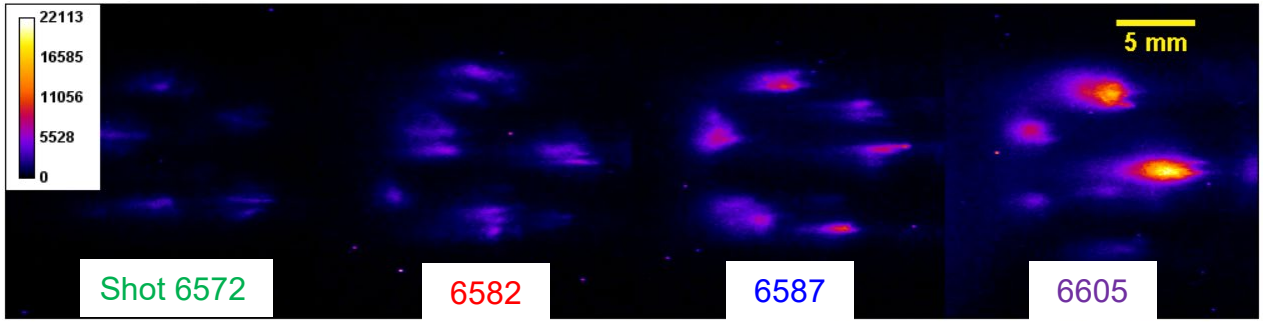
Current turn on delay is reduced as field increases from 40 to 85 kV/cm

We have demonstrated reliable pulsed power operations at several pulse widths with a 15 mm cathode.

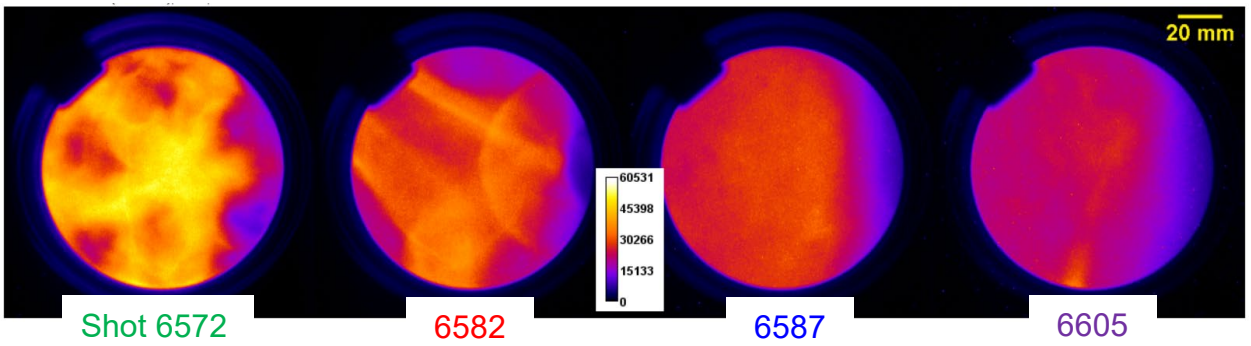


Corresponding gate times

Cathode emission



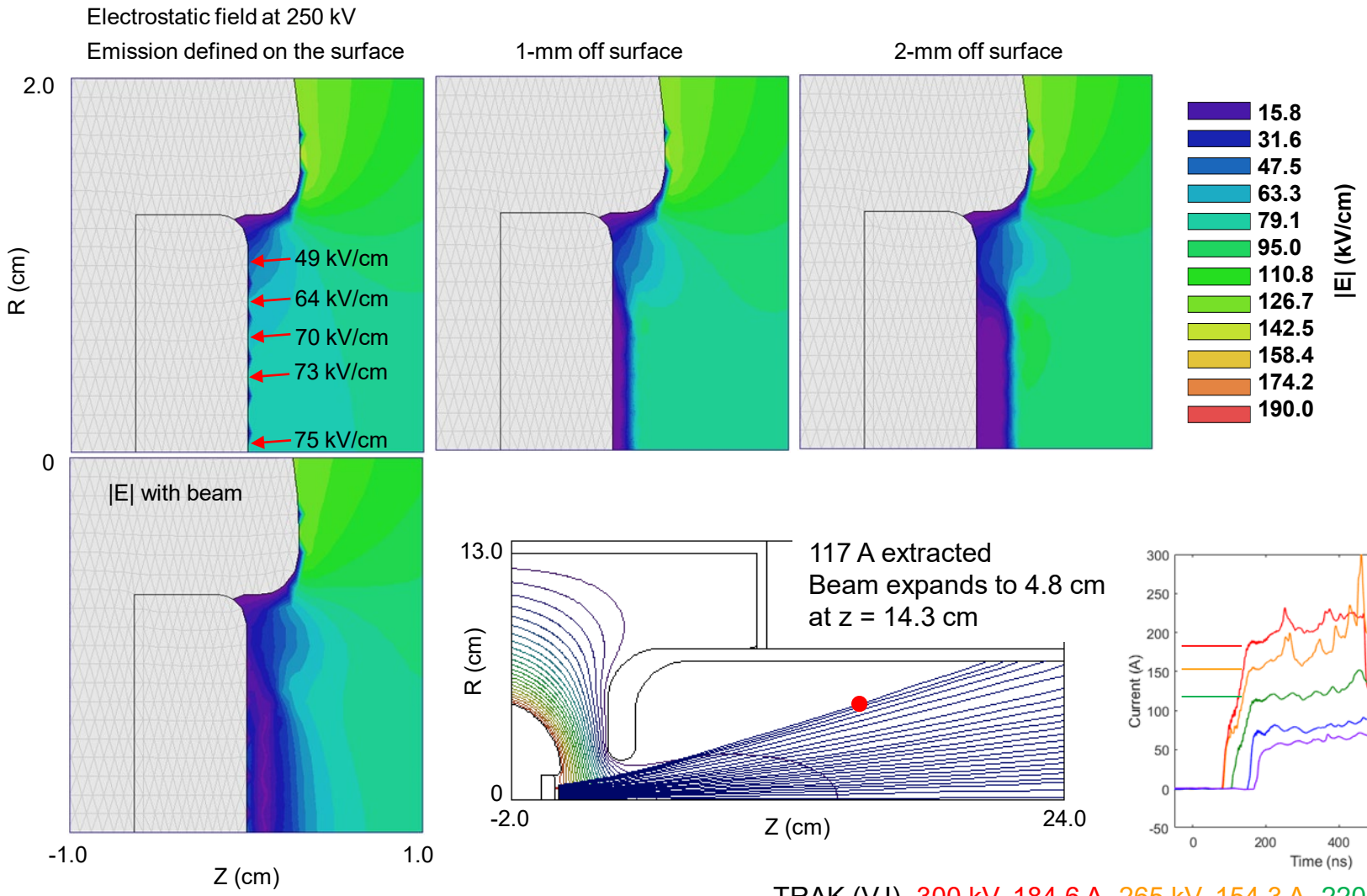
J(x,y), z = 14.3 cm



Shot 6572	6582	6587	6605
t_o = 150 ns Δt = 0.5 μs	250 ns 1.2 μs	350 ns 1.2 μs	750 ns 1.2 μs

We are currently deploying multiframe & streak imaging cameras to study these stochastic phenomena.

TRAK simulations indicate the cathode recess and AK gap are "virtually" decreased by 2 mm in order to match the measured current.



TRAK (V,I) 300 kV, 184.6 A, 265 kV, 154.3 A, 220 kV, 117 A

TRAK is an electro & magneto static code that provides charge particle transport for space charge dominated particle beams.

Conclusion

- **LANL has a platform where field & "hardened" photo emitters can be tested**
  - Long pulse 0.3-2.6 us, low field < 10 MV/m
  - Higher pressure vacuum 10^{-7}-10^{-8} torr
- **We have a good static, theoretical model of the emission from our system.**
- **We have a stockpile of low work function field emitters to test**
  - We would like to minimize surface plasma growth and ohmic heating effects
- **We are looking for suggested initial candidate "hardened" photo emitters**
- **We are working on developing a photogating scheme**

- **We are interested in collaborations, graduate students & postdocs**

END

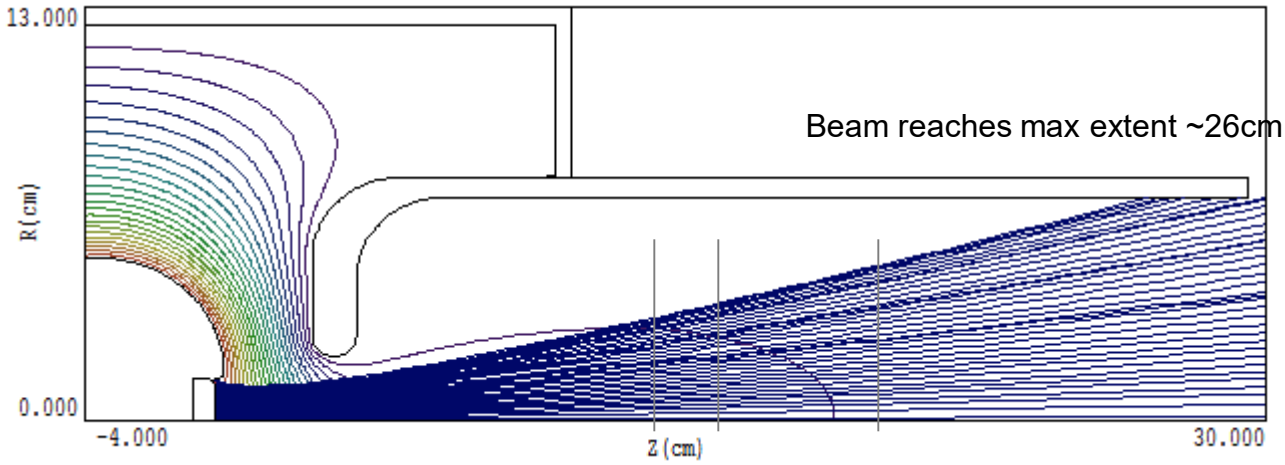
131030 New cathode design

250 kV on diode

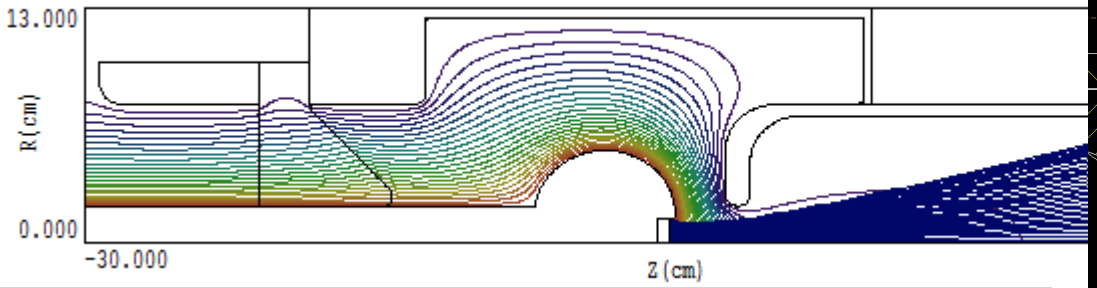
Current for last 5 runs

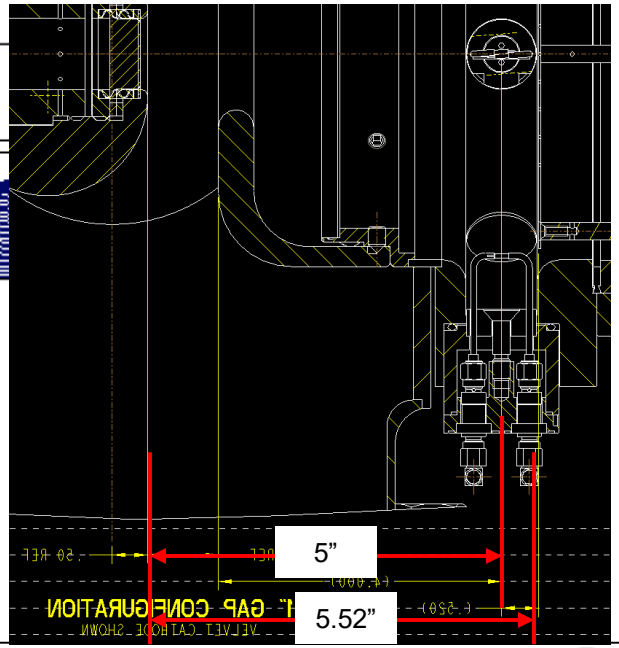
16 1.5124E+02
17 1.5120E+02
18 1.5119E+02
19 1.5120E+02
20 1.5119E+02

File: CTS_New_25mmAK17.TIN
File: CTS_New_25mmAK17.TLS
8 sec run



Beam reaches max extent ~26cm

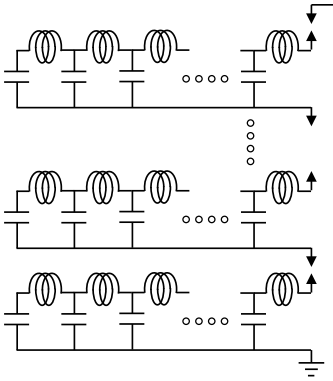


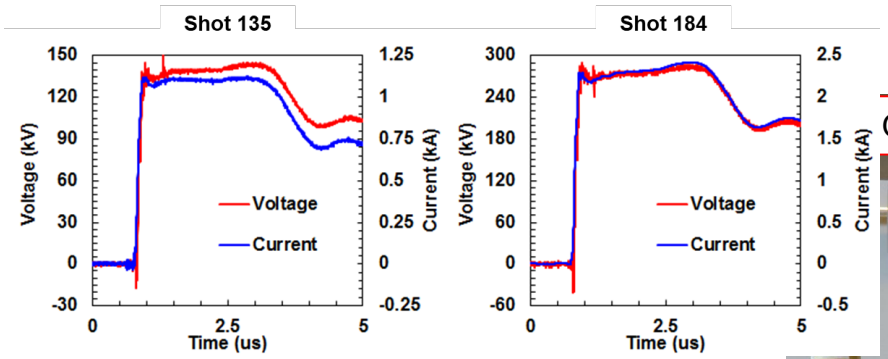


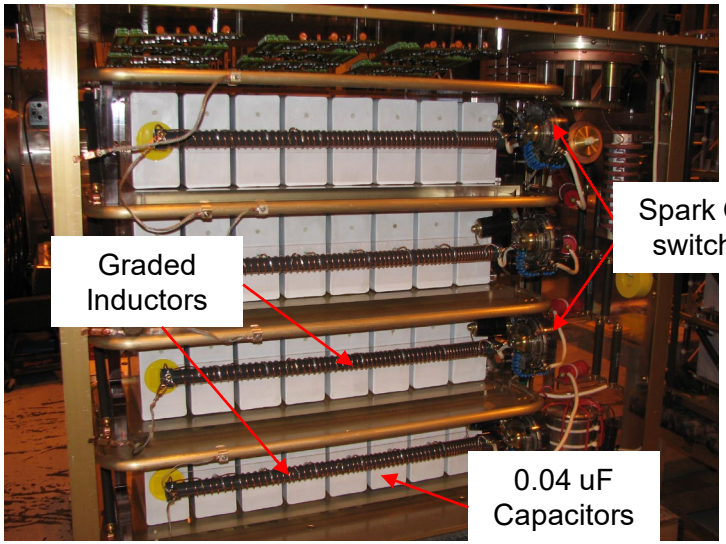
		TRAK Run	131030_ 17				
	z (in)	z (cm)	rMAX (cm)	rMAX (in)	J (A/cm2)	I/hole (A)	K
BPM	5	12.7	3.3	1.299	4.38	0.034	3.01E-06
Pepperpot	5.52	14.02	3.6	1.417	3.68	0.029	2.53E-06
Scint	7.488	19.02	5	1.969	1.91	0.015	1.31E-06

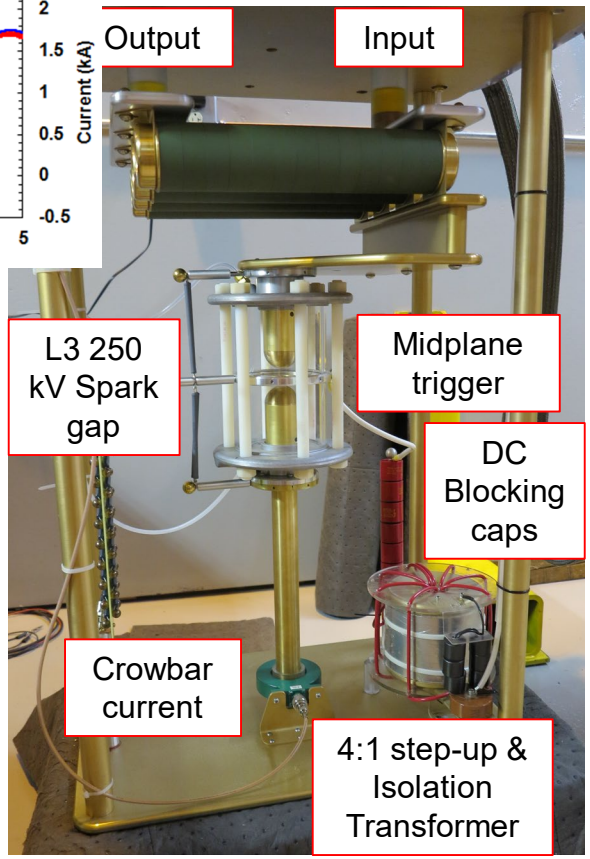
The pepperpot can be retracted 2.275", total z of (7.79") 19.79 cm.

The pulsed power system consists of a 22 Ω Pulse Forming Network (PFN) Marx and crowbar.



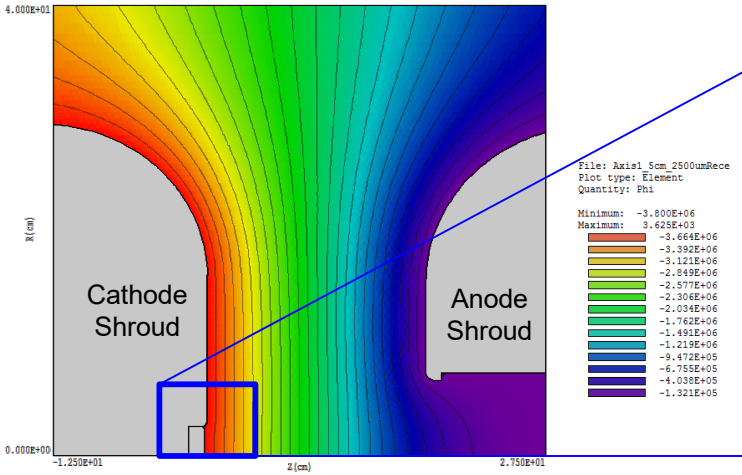




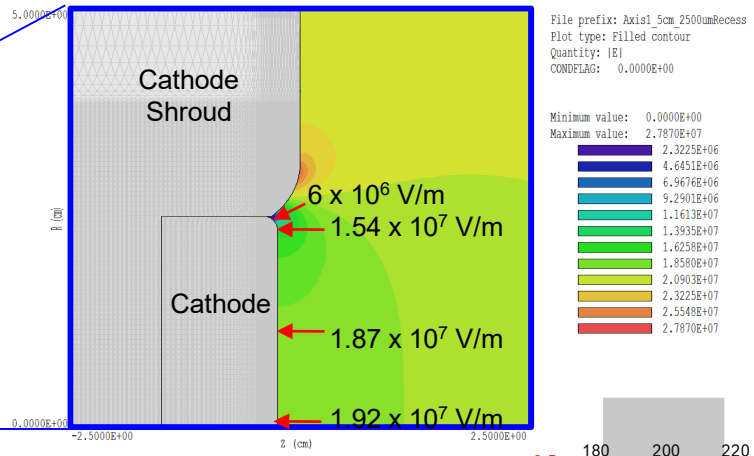


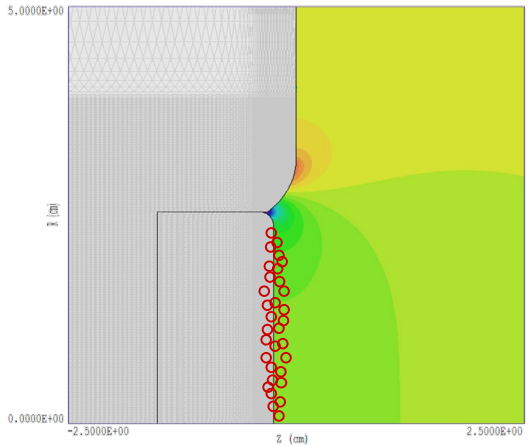
DARHT Axis-1 diode and emission process

Axis 1 diode
Potential lines



Absolute electric fields





At peak voltage (3.8 MV) the peak fields on the cathode surface are around ~150 kV/cm

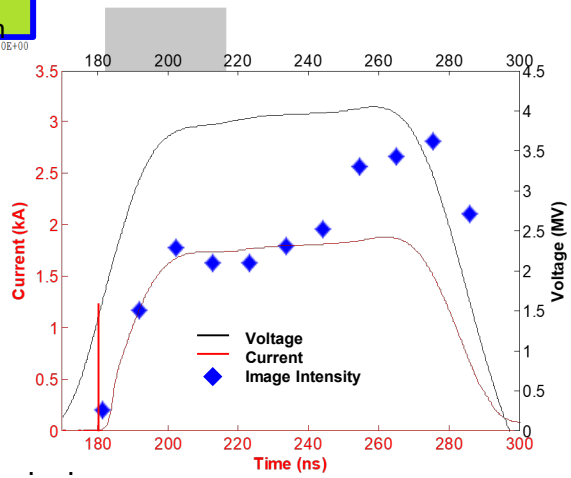
Emission observed at ~40 kV/cm

Process

(1) Strong E-field > 10 kV/cm drives primary electrons off the surface

(2) These electrons desorb and ionize the monolayers of gas on the velvet surface

(3) Avalanche of electrons is accelerated



Field emission
Ionization
Acceleration