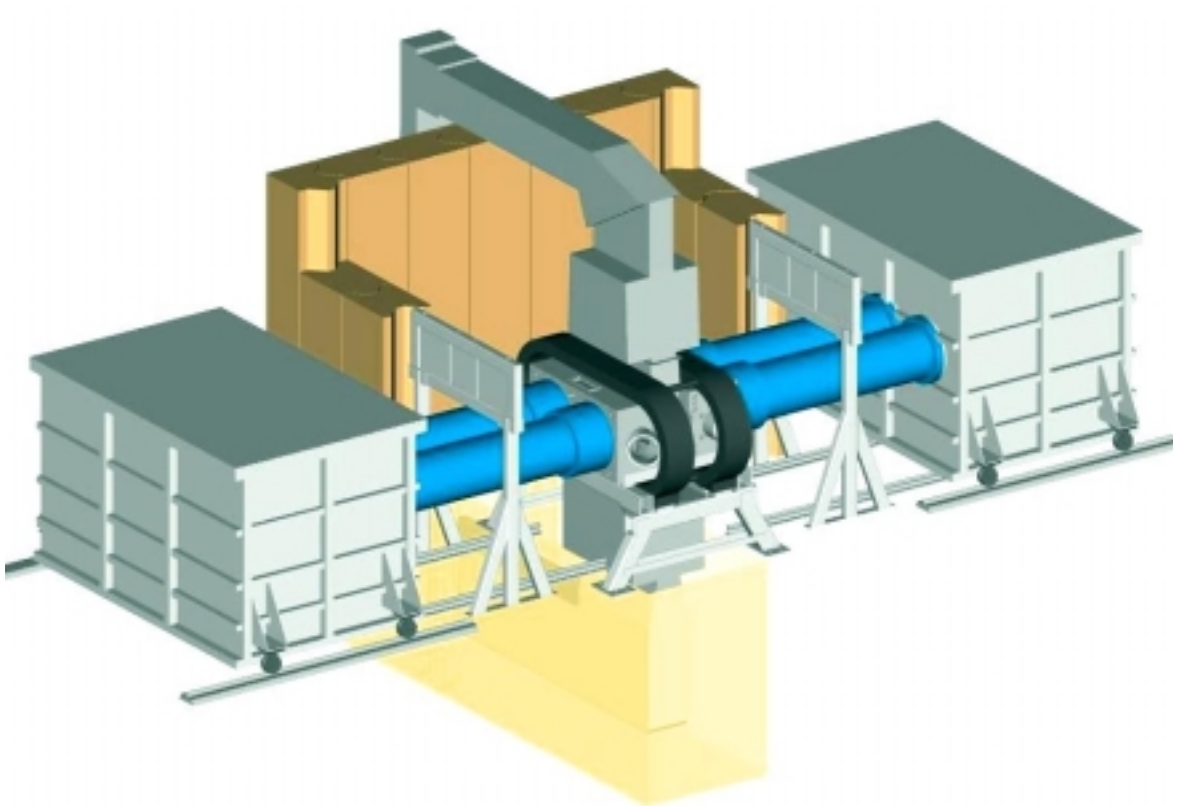
Cathode Development for Electra: A Repetitively Pulsed KrF Laser



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Outline

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- **Brief Introduction to Electra**
- **Electra Cathode Requirements**
  - Turn-on
  - Gap Closure
  - Uniformity
  - Longevity
- **Summary of Experimental Cathode Development - Work in Progress**
- **Experimental Details**
  - Velvet Cathode
  - RHEPP Metal/Dielectric Cathode
- **Additional Cathode Issues**
  - Beam Rotation in External Field
  - Edge Effects
  - Transit Time Instability

Electra is a repetitively pulsed KrF laser that will be used to develop the technology required for an Inertial Fusion Energy (IFE) power plant

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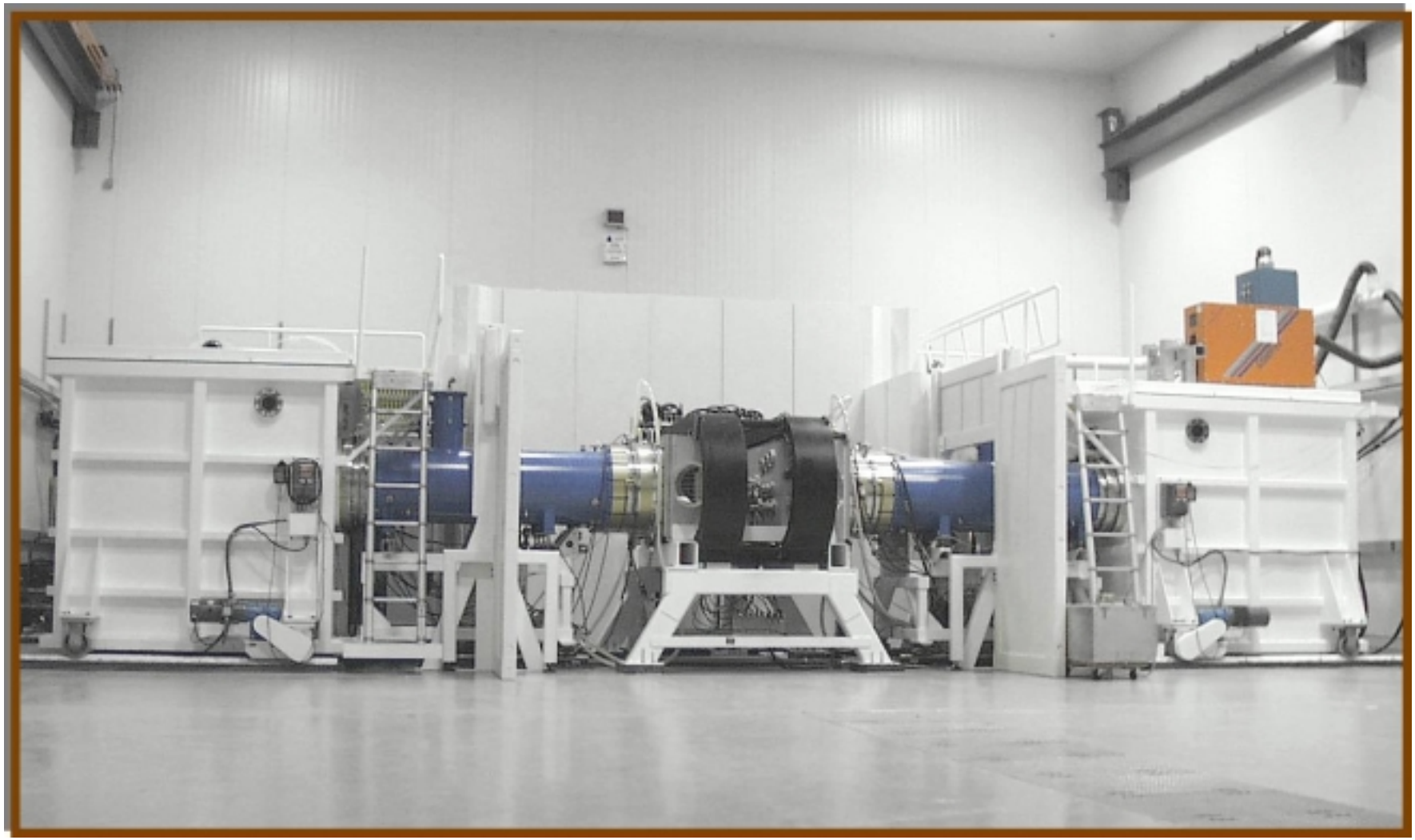

The cathode must meet IFE requirements for efficiency and durability while pumping the laser gas uniformly

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- **Turn-on time: τ_{rise} < 40 ns**
  - Over heating of anode foil heating by low energy electrons
  - ASE (amplified spontaneous emission) may result in laser pre-pulse
- **Gap Closure: must sustain a flat-top voltage pulse for ~600 ns**
  - Need to be in this regime to satisfy IFE requirements of energy on target
  - Pulse must be flat-topped to avoid uneven pumping of laser gas
  - If voltage droops anode foil may be overheated by low energy electrons
  - Poor efficiency
- **Uniformity: variation in J_{beam} < 10%**
  - Local overheating of anode foil
  - Non-uniform pumping may result in spatial non-uniformity in laser pulse
- **Longevity: 3 x 10^8 shots continuous at 5 Hz (2 years)**
  - IFE requirements for reliability and maintenance
  - Rep-rated experiments presently limited by insufficient shielding of “sky shine” radiation

Diagnostics

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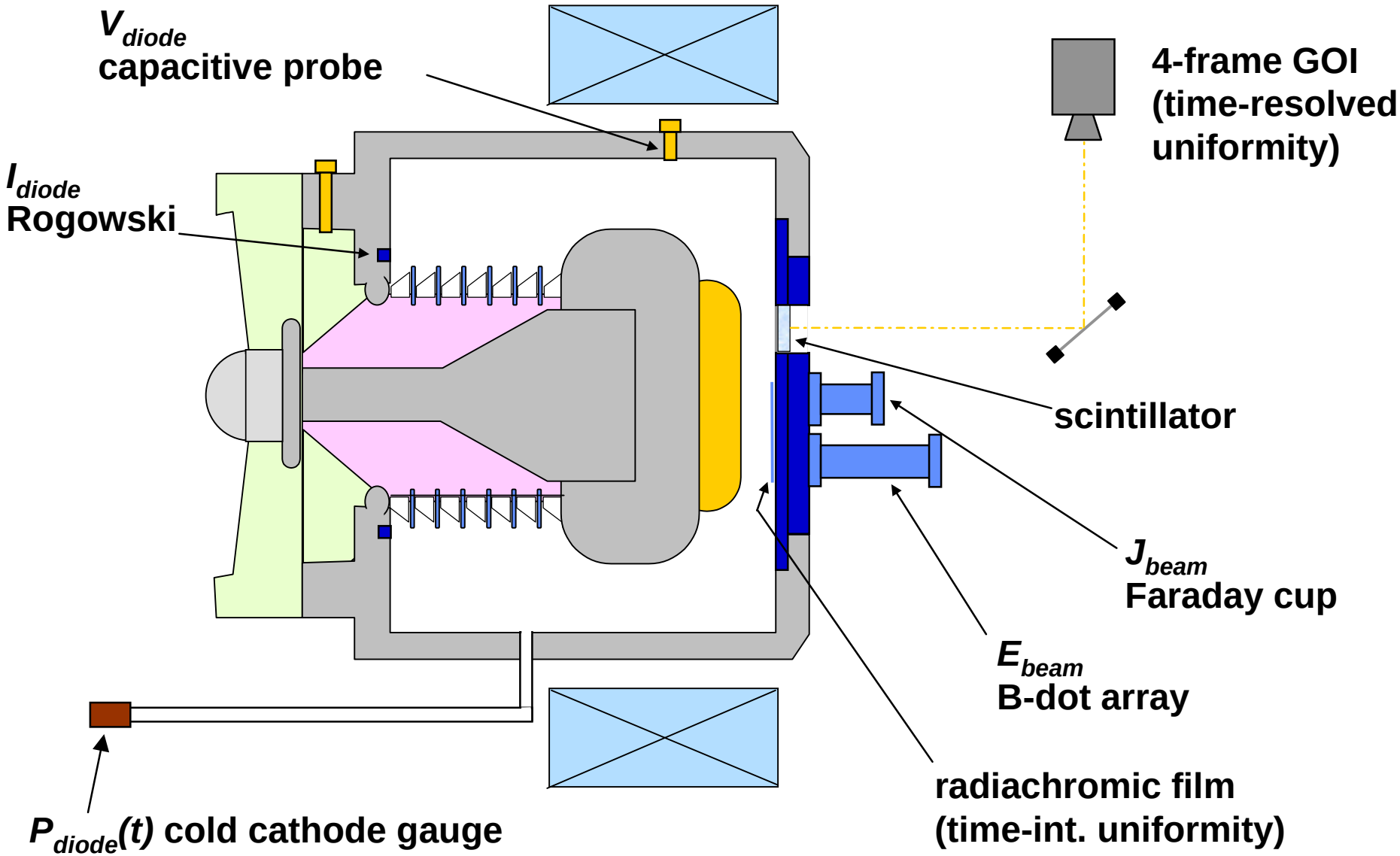

Experimental Standards

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- Beam nominally V_{diode}=500 kV, I_{diode}=90-100 kA, T_{pulse}= 100 ns flat-top
- External magnetic field, B_{ext}~1.4 kG
- Initial diode pressure (8 inch Cryo-pump), $P_{diode} \leq$ 8E-6 T
- AK gap is ~5.2 cm
- Anode is aluminum (1 mil foil, 1 mil aluminized Kapton, or cooled Al plate)
- For these experiments all cathodes are 27 cm x 97 cm

We have looked at 17 types of cathodes/materials

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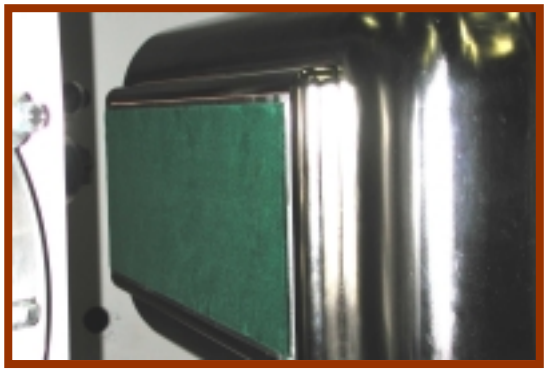
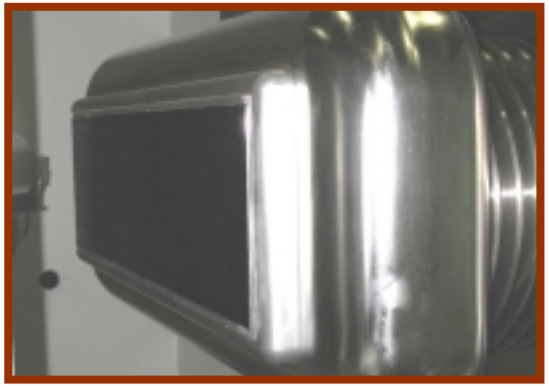
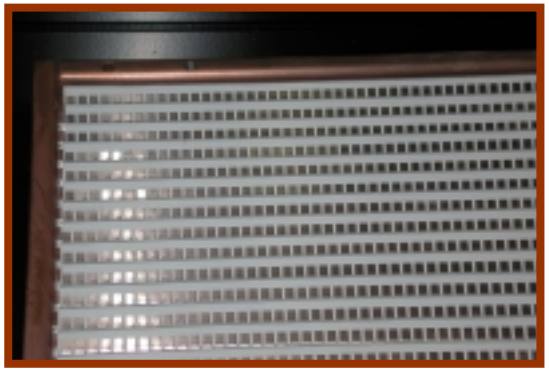
- Dielectric Fiber
  - Double Velvet
  - Other Velvets
  - Glass
- Carbon
  - Fiber
  - Cloth
  - Foam 100 ppi
  - Foam 500 ppi
  - Flock (2%)
- Metal/Dielectric
  - Ceramic/Honeycomb
  - RHEPP
  - Fine scale RHEPP
- Patched Cathodes
  - Silicon Carbide
  - Carbon/Carbon Fiber
  - Diamond-like Carbon
- CsI Coated Patches
  - Double Velvet
  - Carbon/Carbon ESLI
  - Silicon Carbide







Comparison of Turn-On Times

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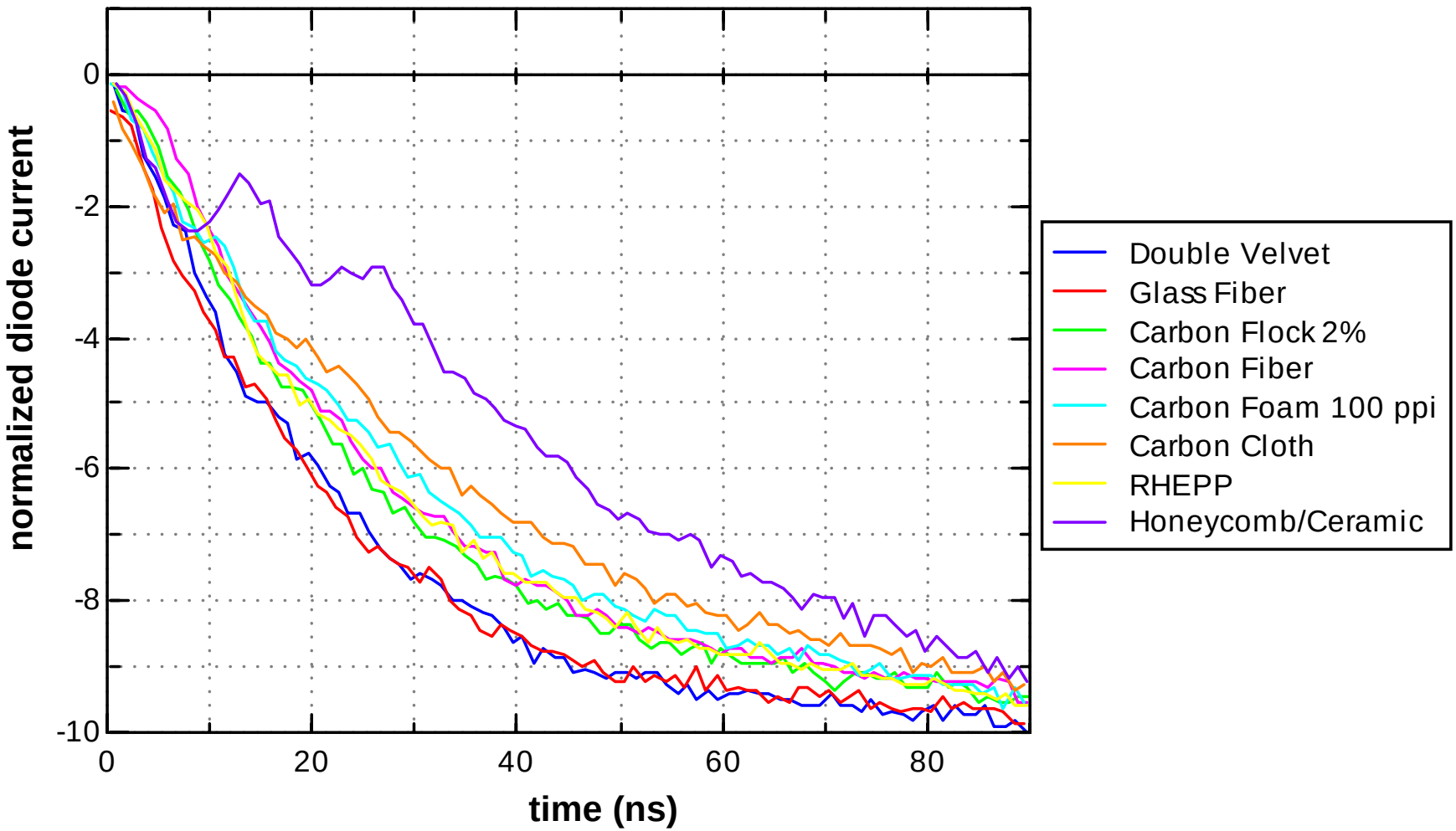

Comparison of Uniformity and Longevity

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	UNIFORMITY		LONGEVITY	
CATHODE	Current Density Variation (rad. film)	No. Shots	Change in V or I first-last ?	Pressure @ end of run
Double Velvet	6%	500	No	2.00E-04 →
Glass Fiber	25%	….	….	….
Carbon Flock (ESLI)	15%	800	Slight	2.40E-05 →
Carbon Fiber (Eusebio)	41%	3100	No	2.30E-05 →
Carbon Foam (100 ppi)	19%	….	….	….
Carbon Cloth	57%	….	….	….
RHEPP	50%	300	Slight	2.00E-05 →
Fine Scale RHEPP	25%	….	….	….
Honeycomb/Ceramic	32%	….	….	….

- **Velvet is standard for uniformity**
- **Carbon Flock uniformity promising - conditioning may enhance uniformity**
- **RHEPP and Carbon fiber longevity is apparent**
- **Improved x-ray shielding (in construction) will allow 10^4 - 10^5 shot runs**

Comparison of Diode Impedance History

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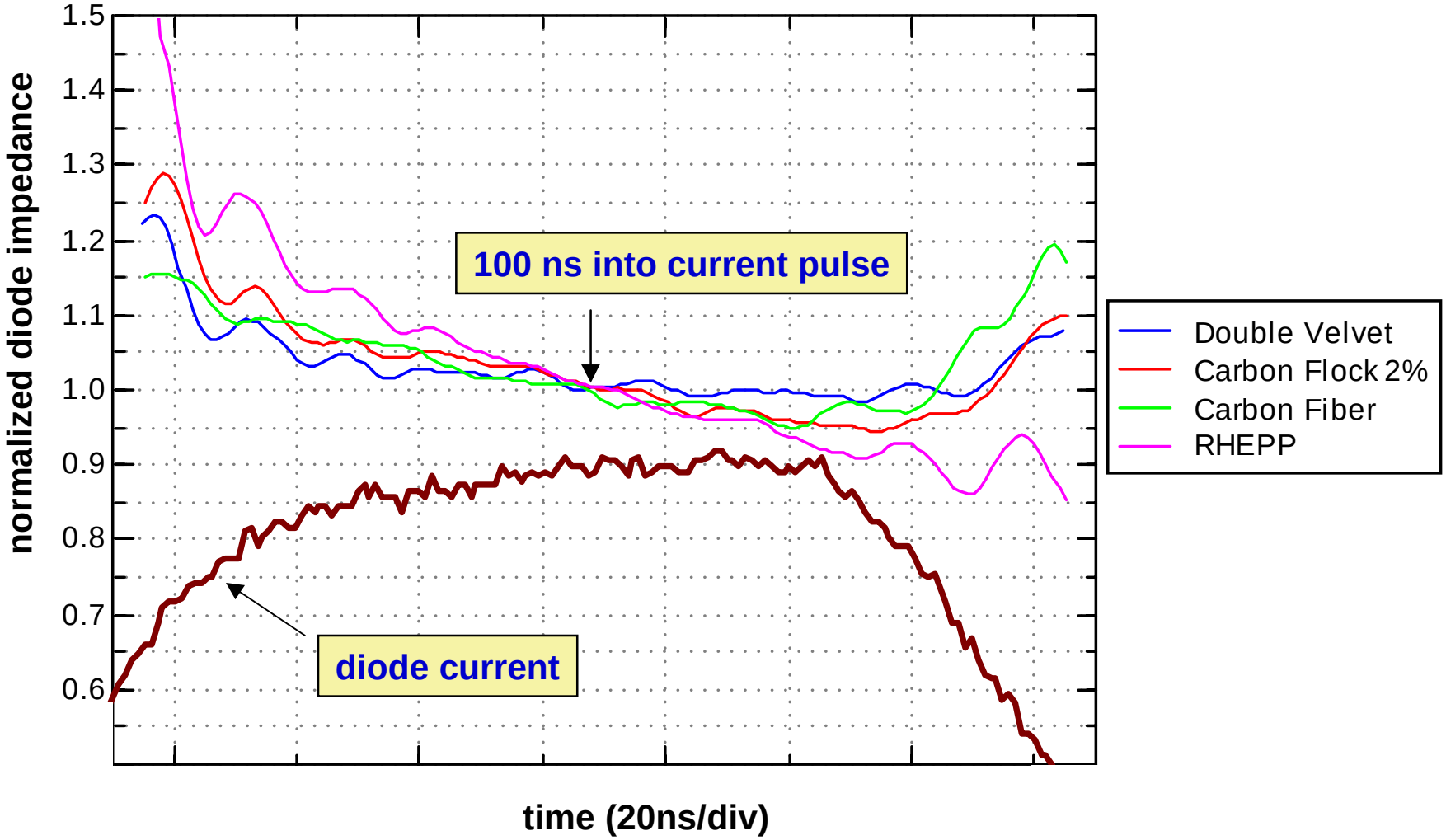

NRL Velvet Cathode

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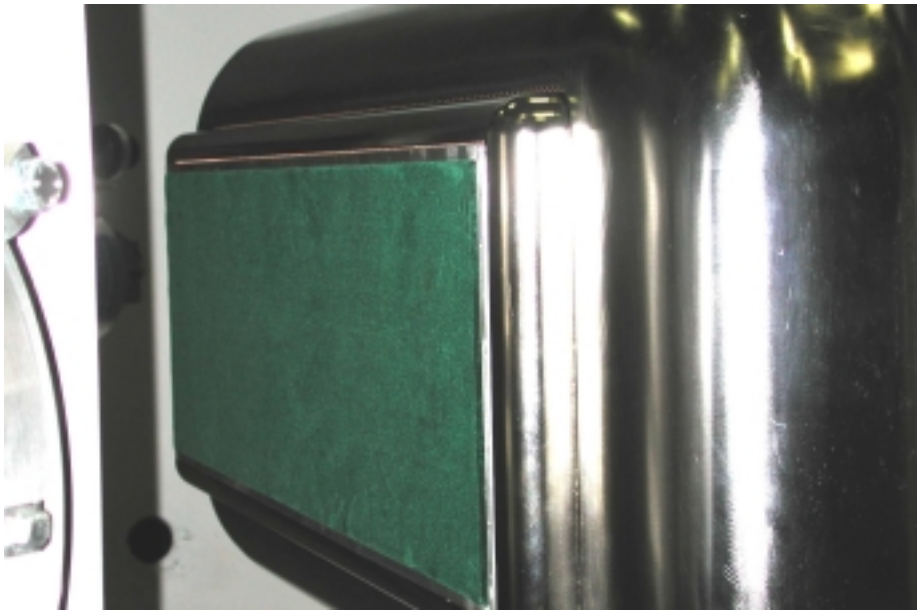
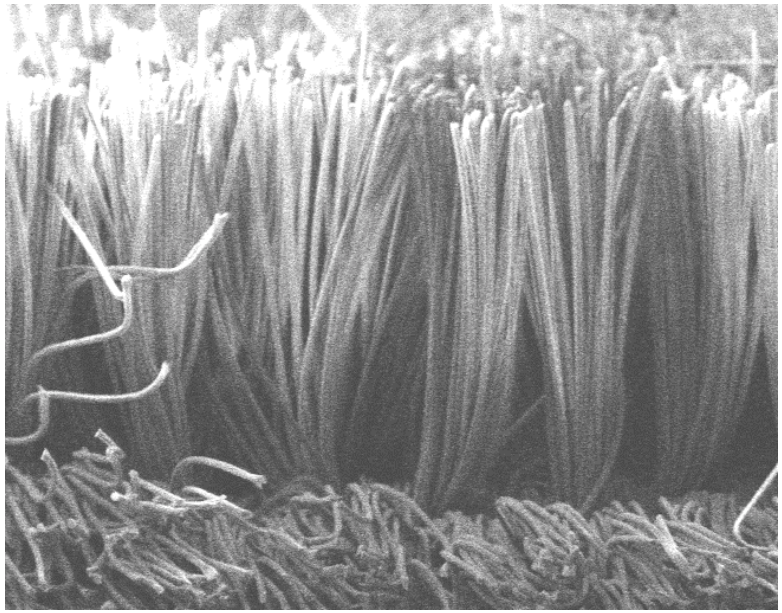
- Standard velvet (Eagle brand, double velvet, superfine quality)
  - 18 mm fiber diameter, 4.4% volume coverage





Velvet : Turn-on and Gap Closure

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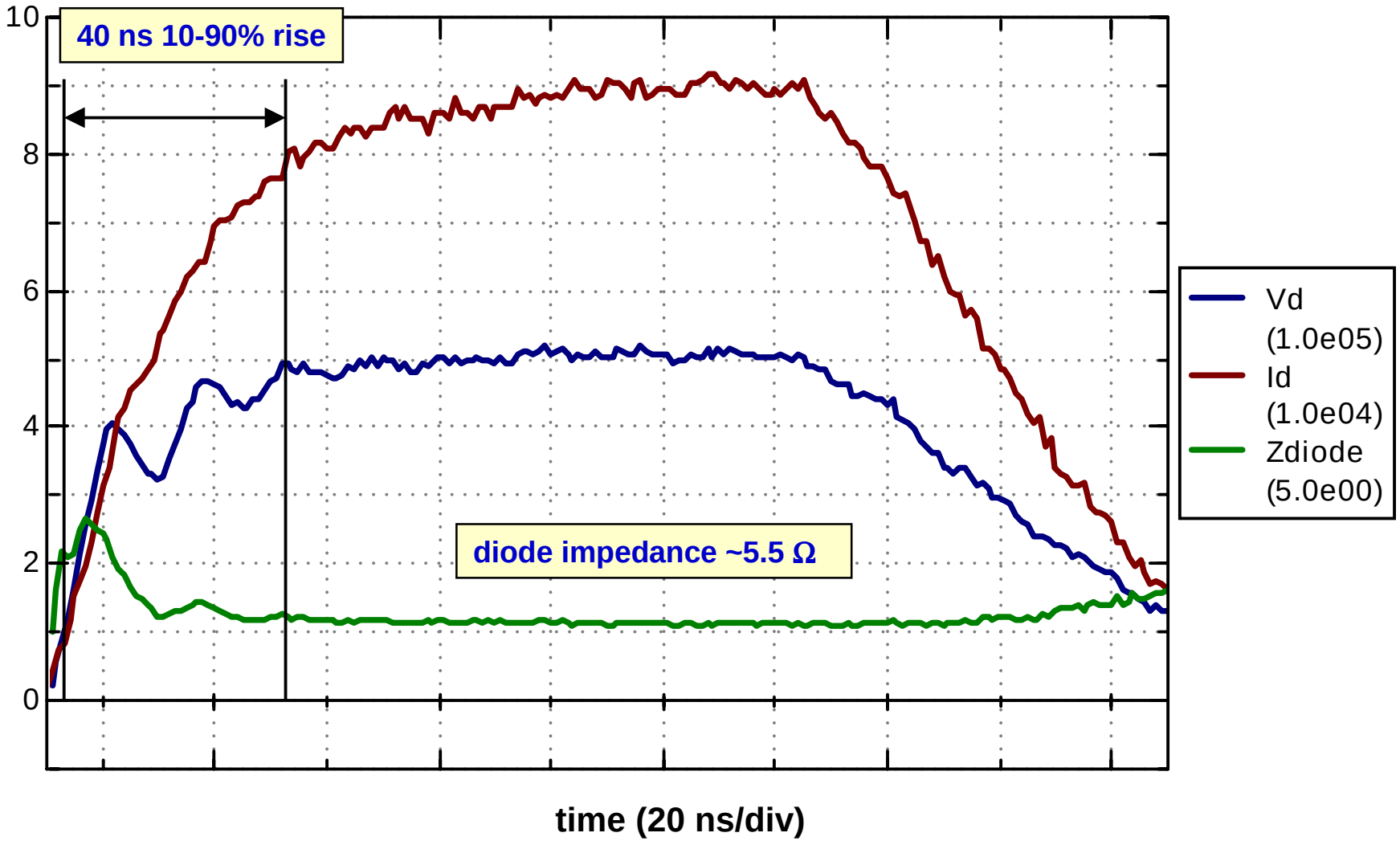

Velvet : Time Integrated Uniformity

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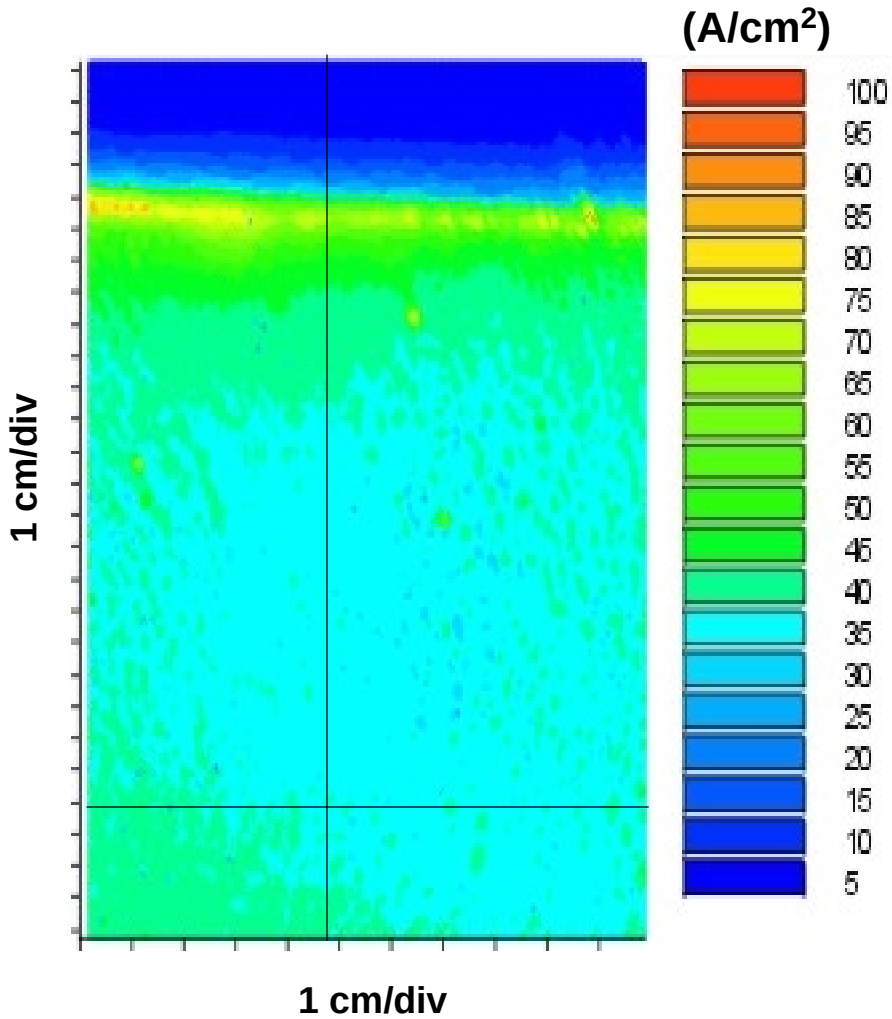

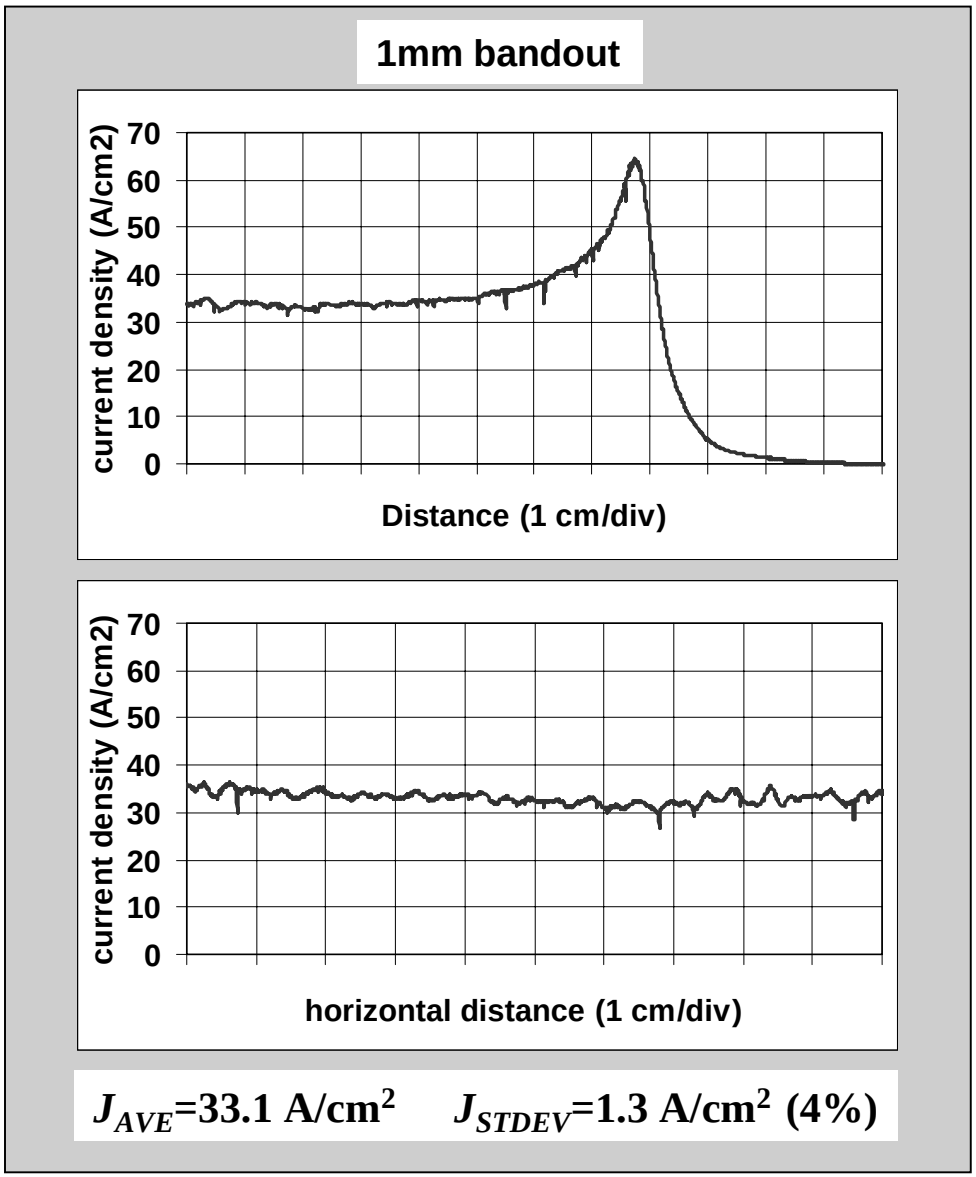

Velvet : Time Resolved Uniformity

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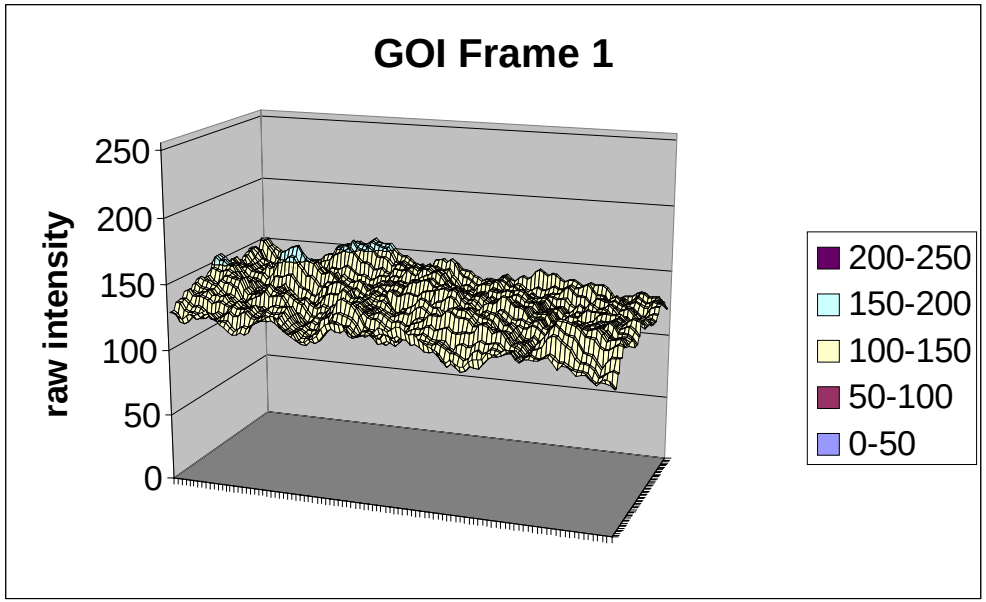

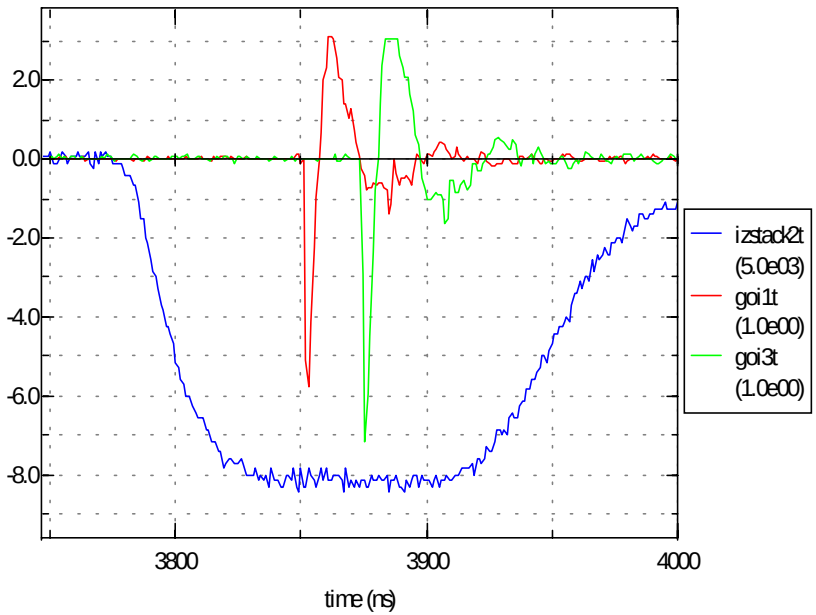

- **Direct illumination of scintillator: EJ-212 w/ honeycomb**
- **2 ns gate, gain=3, t_{pulse}= 65 ns**
- **100 x 50 pixel bandout: INT_{mean}=131, INT_{stdev}=8.2 (6%)**

- **Faraday Cup Data: J_{mean}=31.0 A/cm^2, J_{stdev}=1.98 A/cm^2 (6.3%)**

Velvet: Longevity

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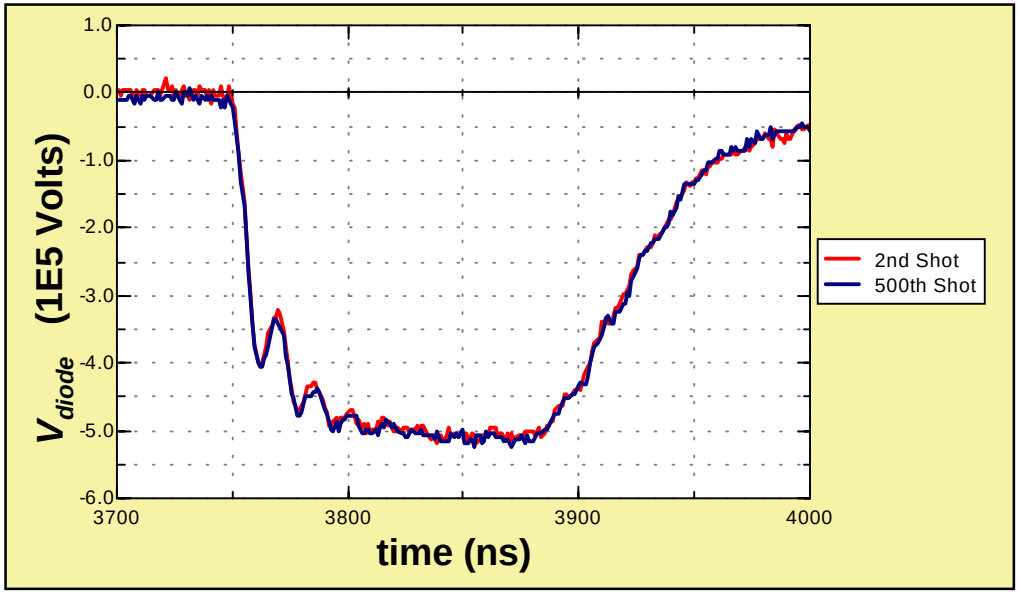
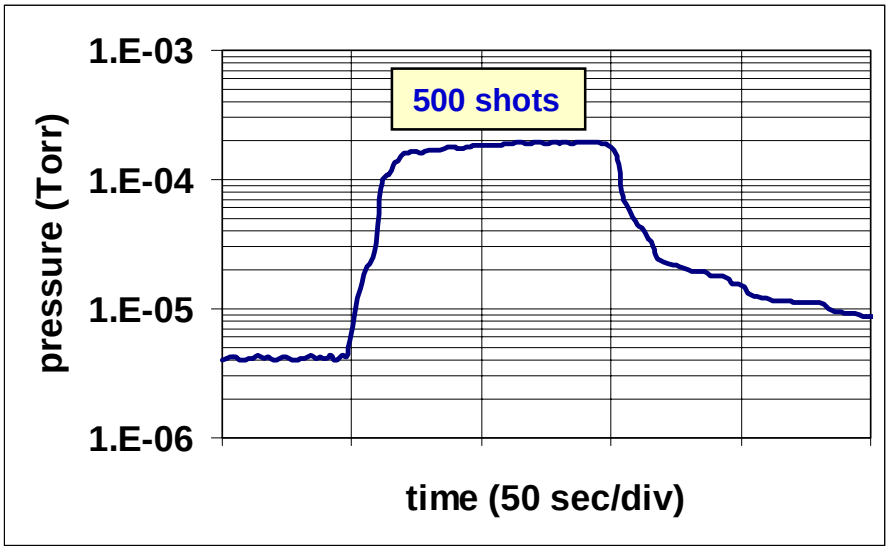


- Diode voltage and impedance unchanged after 500 shots at 5 Hz
- Cathode turn-on unchanged at 500 shots



- Diode vacuum reaches ~ 2E-4 Torr and stabilizes
- Uniformity at 500 shots: unknown

RHEPP Metal/Dielectric Cathode

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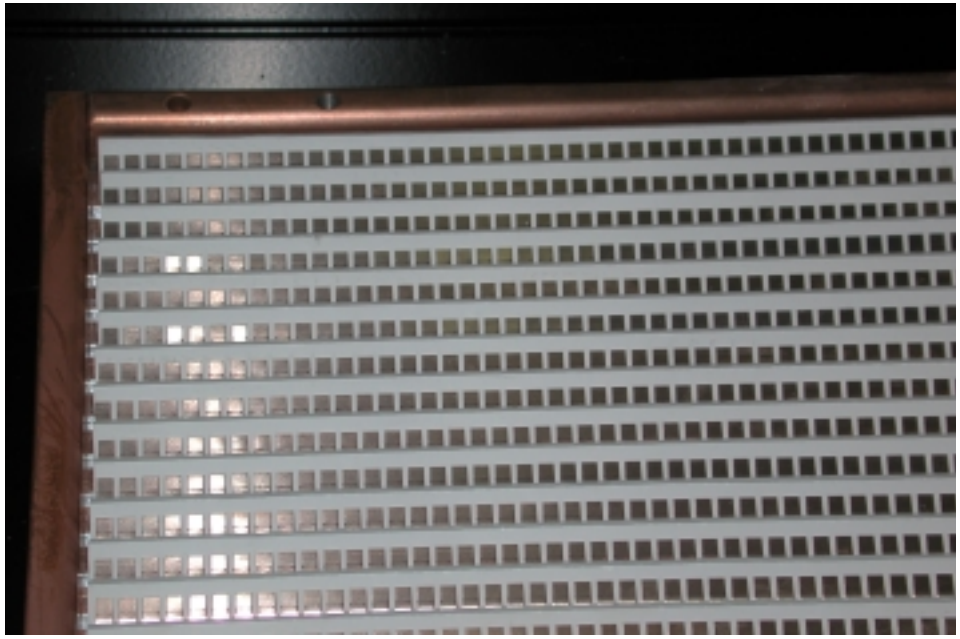
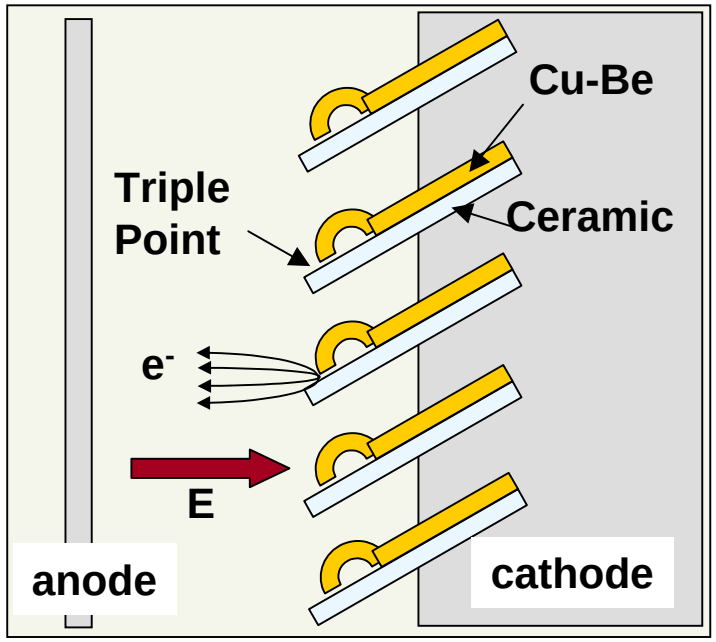
- Metal/Dielectric cathode based on RHEPP design. Emitters spaced at 1 cm and oriented 30 degrees from vertical. Uses 99.5% alumina dielectric and beryllium copper fingerstock (shown in pic).

- Finer scale version with 2 times the number of emitters in both dimensions also constructed.





RHEPP Metal/Dielectric: Turn-on and Gap Closure

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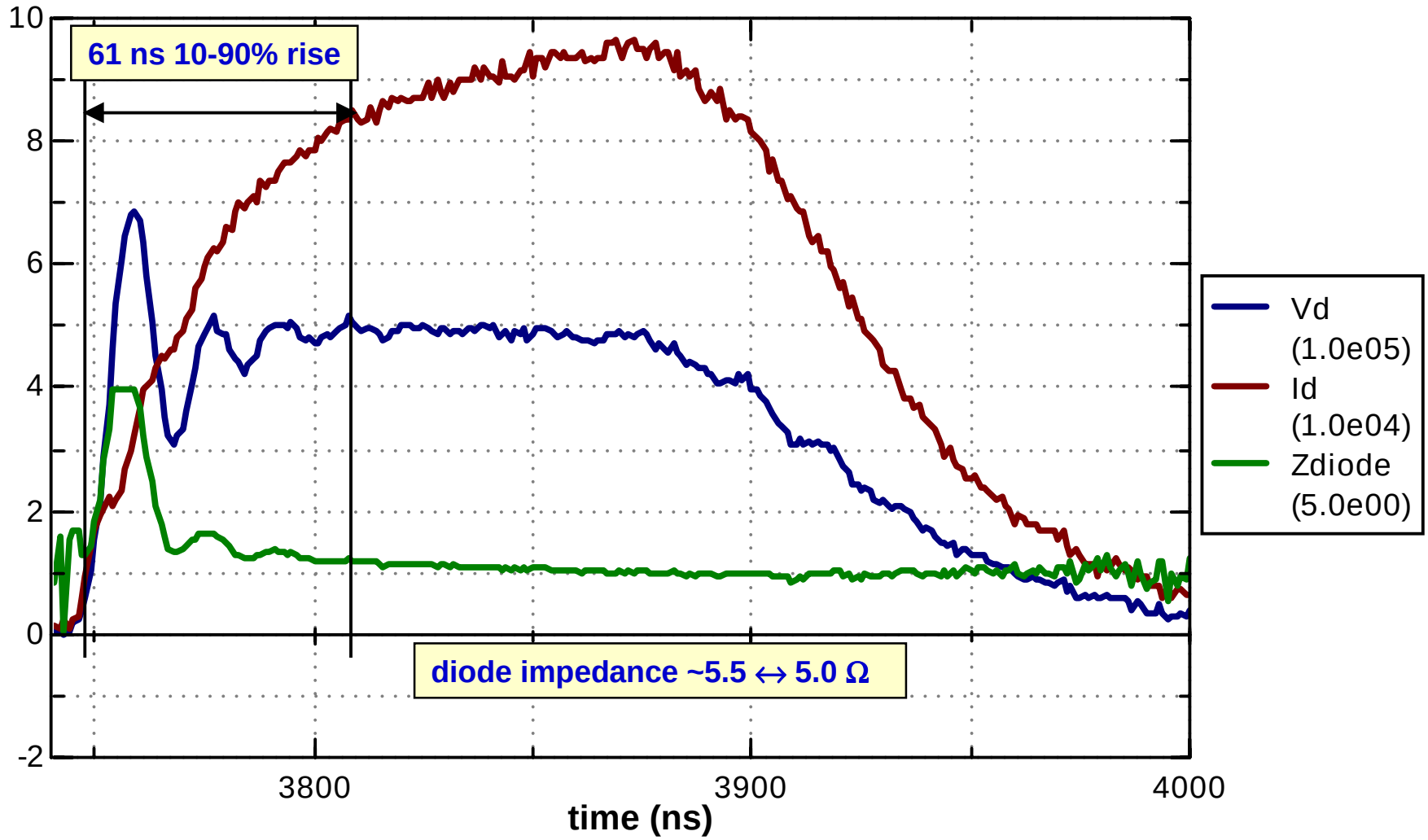

RHEPP Metal/Dielectric: Uniformity

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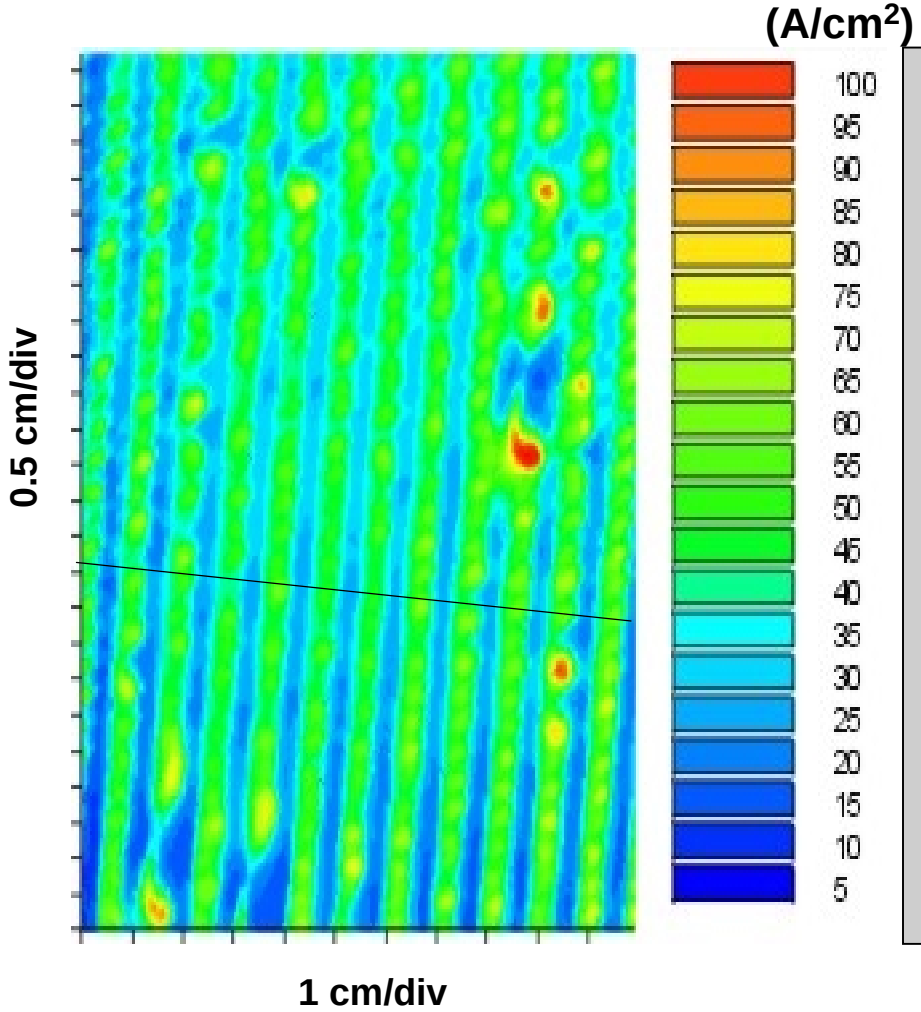

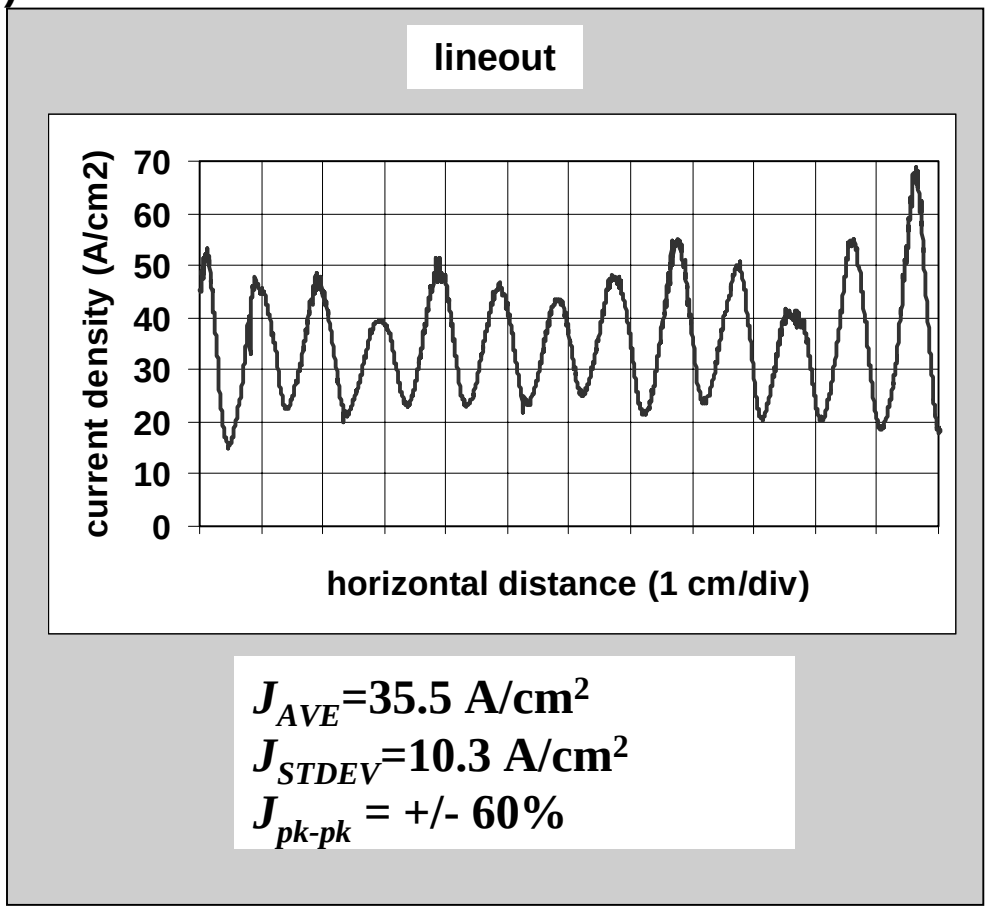

- **Faraday Cup Data: J_{mean}=32.2 A/cm², J_{stdev}=2.03 A/cm² (6.3%)**

RHEPP Metal/Dielectric : Time Resolved Uniformity

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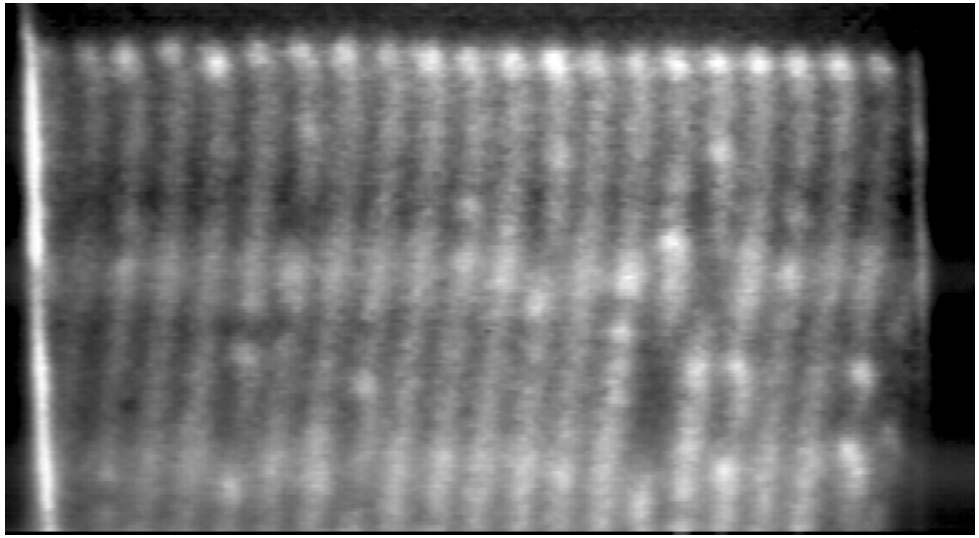

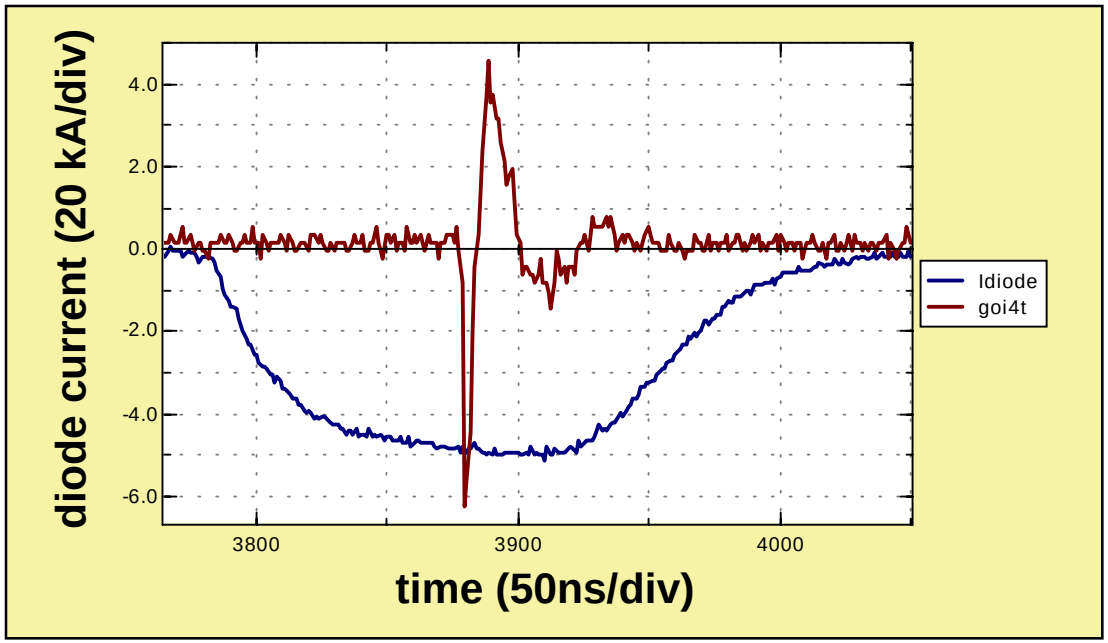

- 4 mil Ta convertor, EJ-212 scintillator
- 2 ns gate, gain = 4
- t_{pulse}= 100 ns

RHEPP Fine-Scale: Time Integrated Uniformity

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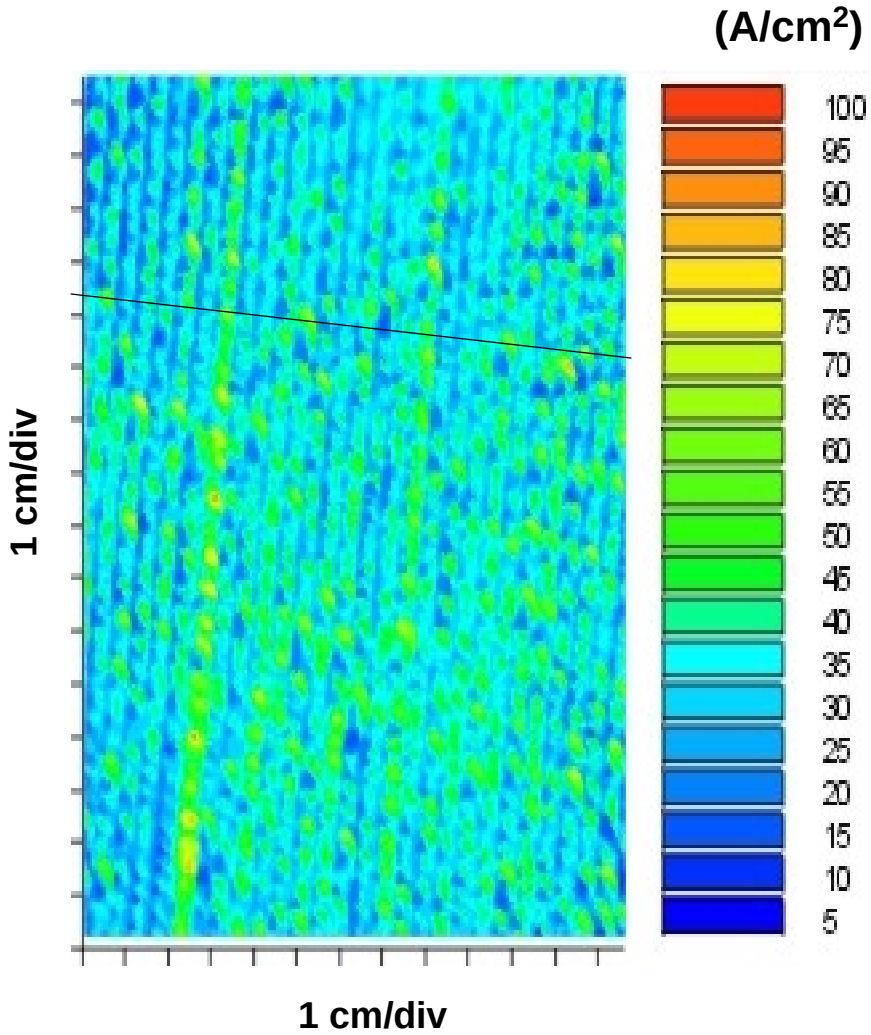

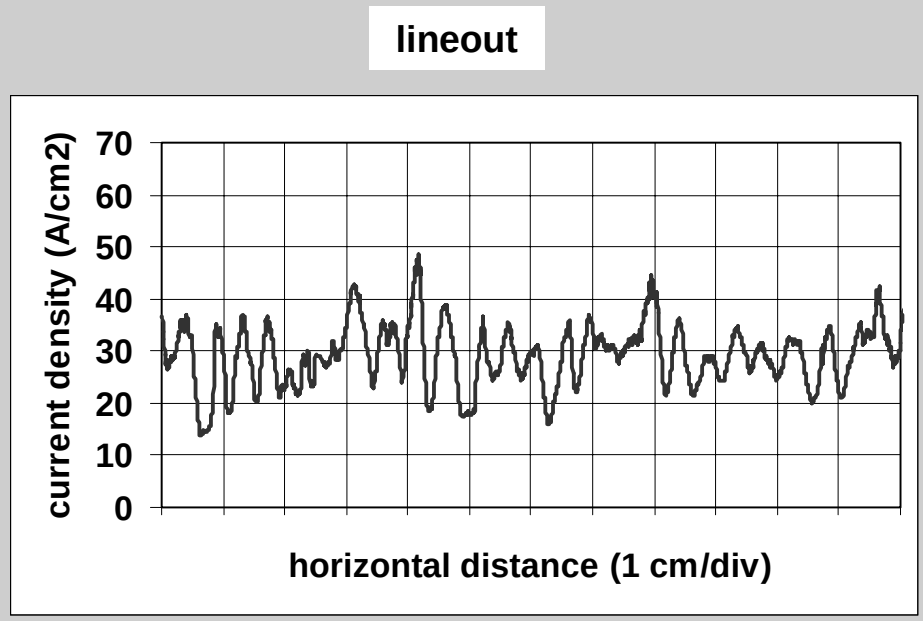

J_{AVE}=29.1 A/cm^2
J_{STDEV}=6.0 A/cm^2 (20%)
$J_{pk\text{-}pk}$ = +/- 30%

RHEPP Metal/Dielectric: Longevity

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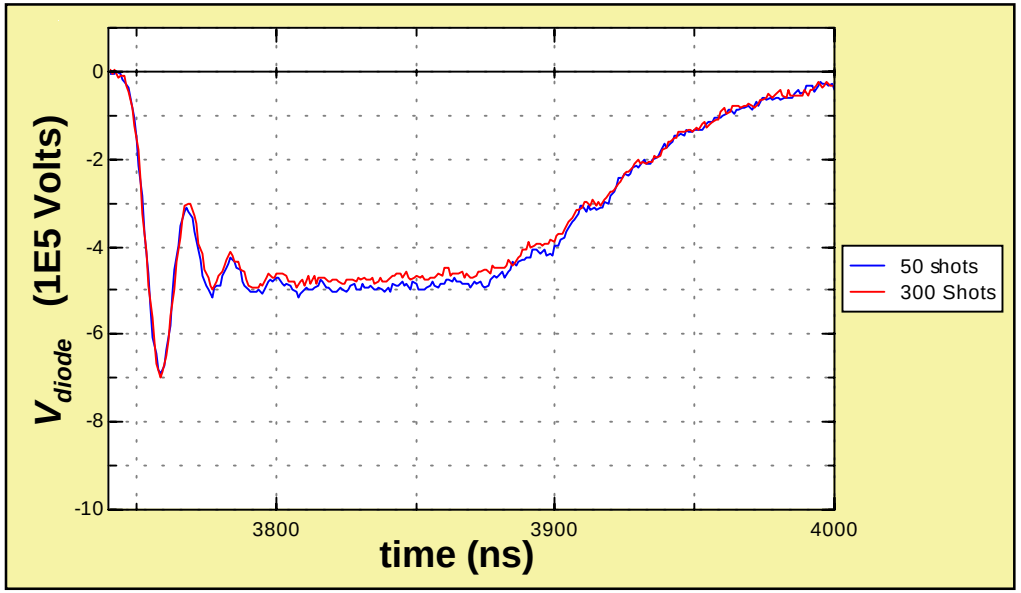
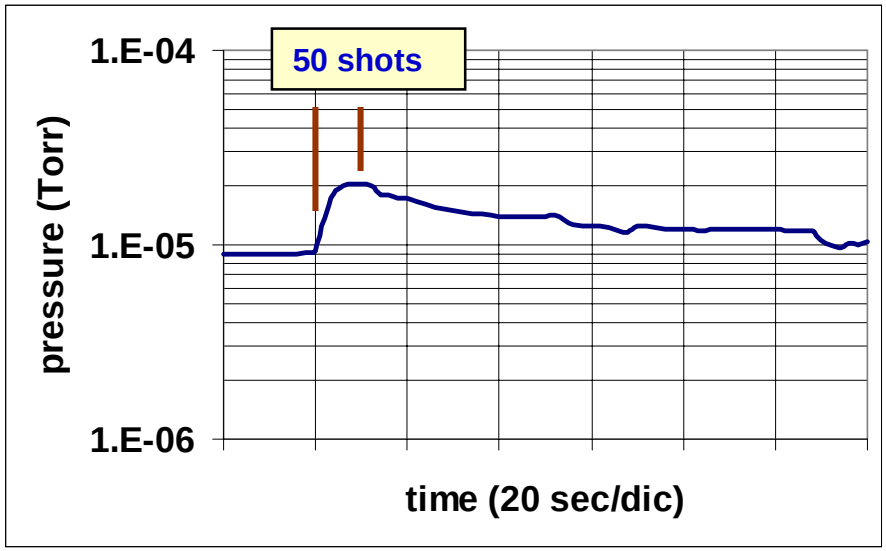


- Diode voltage unchanged throughout 300 shot run at 5 Hz
- Expect cathode to have a lifetime of ~10^8 shots based on Russian data



- Diode vacuum: initial base pressure higher (ceramic); pressure steady at ~2E-5 Torr for 50 and 300 shot runs
- Uniformity at 300 shots: unknown

Additional Requirements for KrF Laser Cathodes

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- **Magnetic guide field required to prevent beam from pinching**
  - **Cathode Compatibility with external guide field (1-3 x B_{self})**
  - **Beam rotation - must get through hibachi structure efficiently**
  - **Possible solution: rotate cathode to compensate**
- **Transit time instability**
  - **Large area, parallel-plane, low impedance diodes are vulnerable**
  - **Causes spatial and temporal non-uniformities in e-beam resulting in poor diode efficiency and anode foil overheating**
  - **Possible solution requires columnar or patched cathode emitters**
- **Edge effect: $J_{edge} \sim 2J_{beam}$**
  - **Anode foil damage/overheating**

Elimination of edge effects will extend anode foil lifetime and allow more uniform pumping of the laser gas

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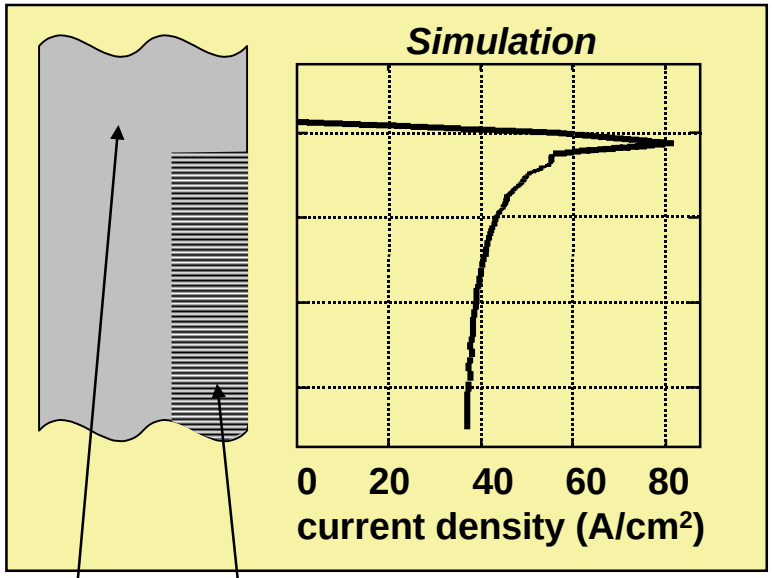
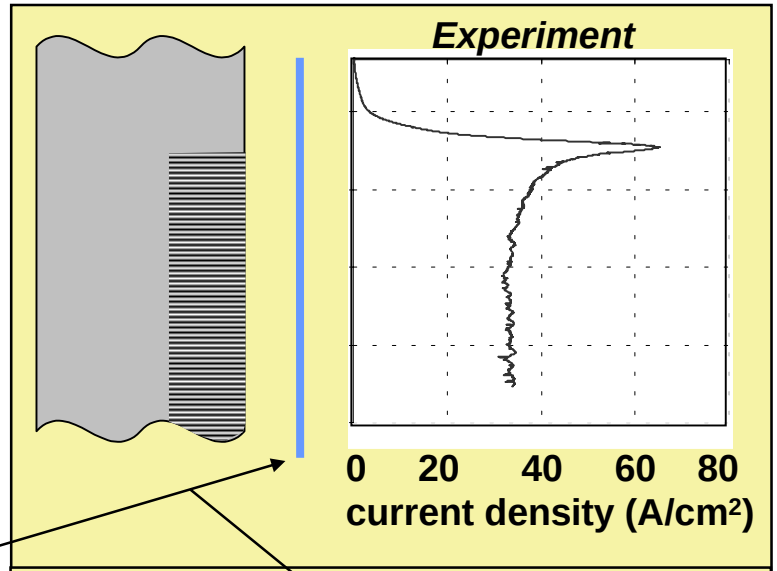
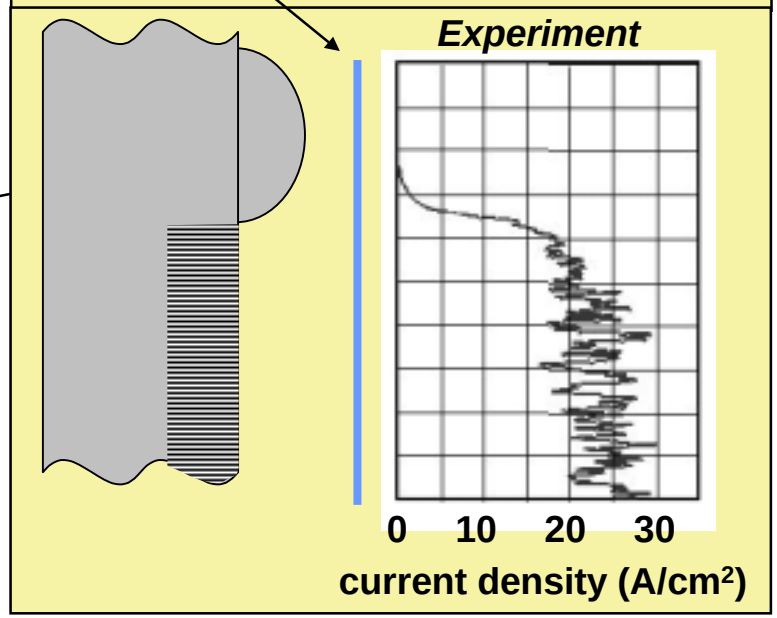


Base Emitter Radiachromic film





A metallic field shaping element reduces the electric field at the boundary, suppressing the high current density beam edge.

Status Summary

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- Velvet sets standard for turn-on, gap closure, and uniformity but probably won't meet longevity requirements.
- RHEPP metal dielectric can produce 10^8 shots but uniformity needs to be improved.
- Carbon flock uniformity looks promising but longevity is still a question.
- Working on an in-vacuum diagnostic to look at uniformity vs. longevity.
- Improve optical diagnostics to get more time resolved uniformity data and to look at turn-on physics.
- Improved x-ray shielding will allow 10^4-10^5 shot runs on Electra