Charge Lifetime, Emittance, and Surface Analysis Studies of K_2CsSb Photocathode in a JLab DC High Voltage Gun

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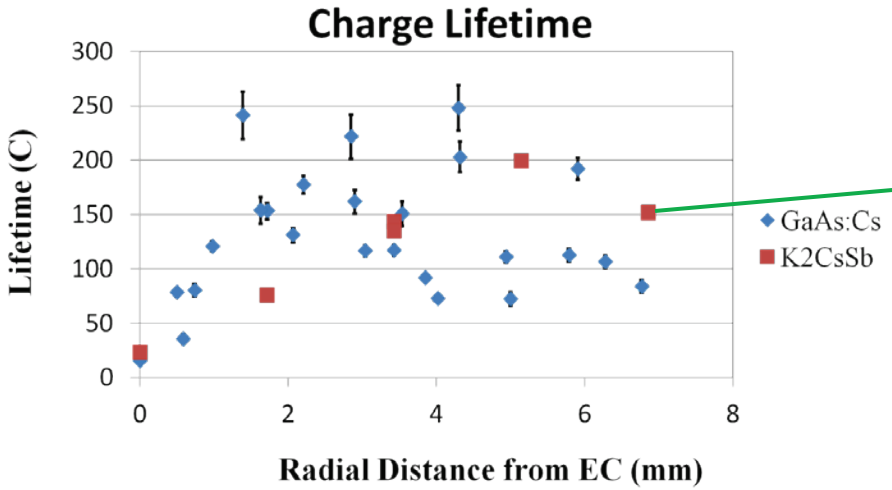
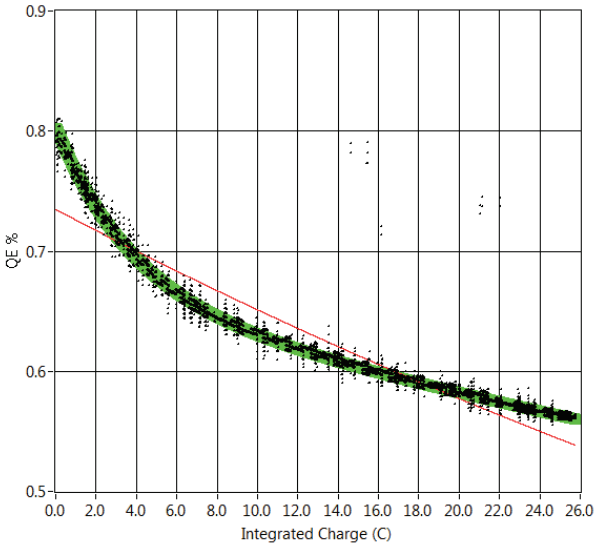
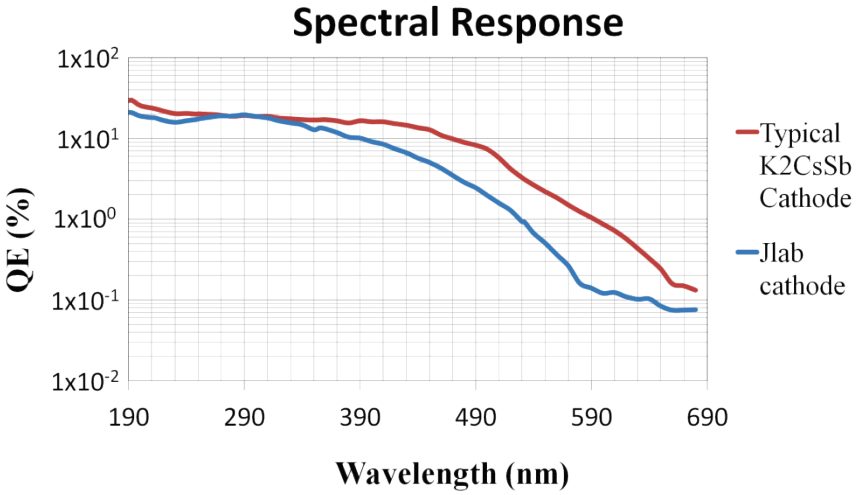
Story starts with PAC11 results

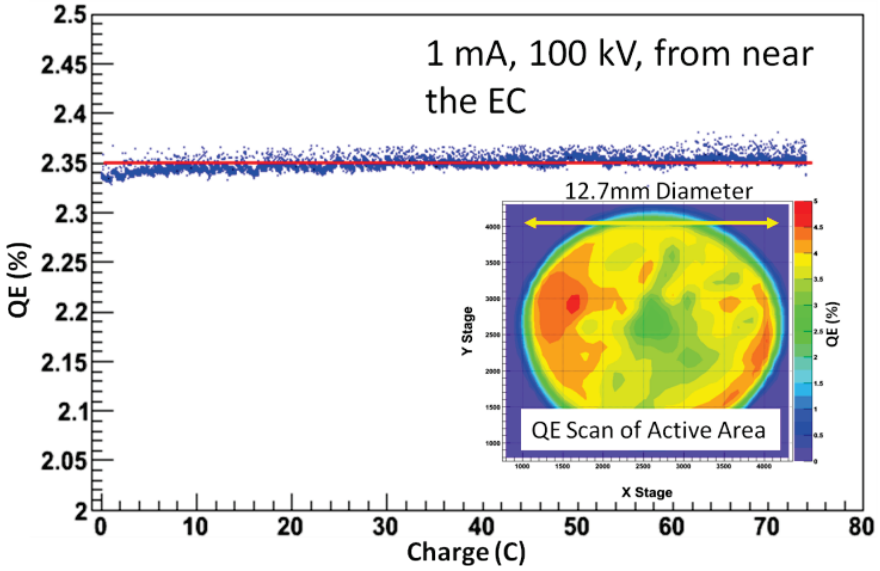


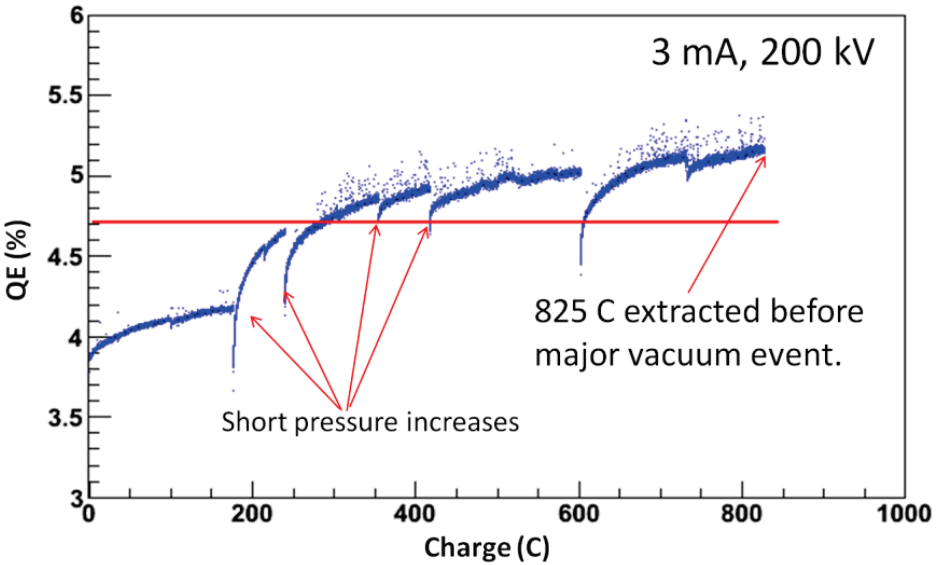


- **Lifetime data taken at 100kV, 1mA, 532nm**
- **Similar performance to GaAs, not exactly what was hoped for…**
- **However, exact stoichiometry of cathode unknown, as K dispenser depleted during deposition.**



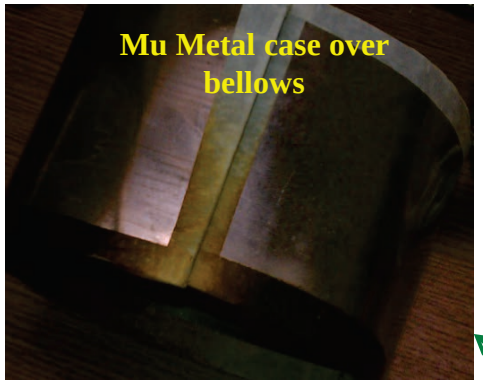
Initial 440 nm, 850 μm spot size results



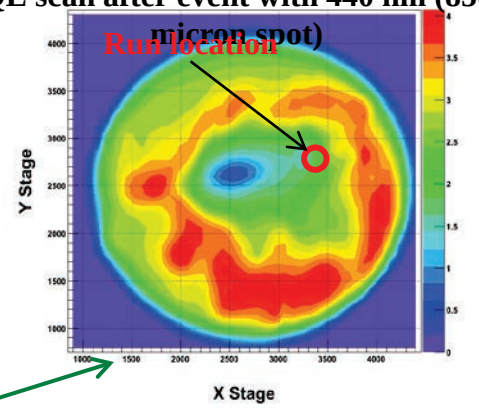


- No QE decay was observed for all 1 mA runs at up to 100 C extracted at 100 and 200 kV bias voltages and every spot tested on the cathode, even from the EC.
- QE actually increases during the 3 mA run despite several short pressure increases (vacuum events) in the beamline and gun chamber that temporarily reduced the QE.
  - Short pressure/vacuum events are due to full active area and poor spatial quality of blue laser beam (halo).

And then problems…(but not really)



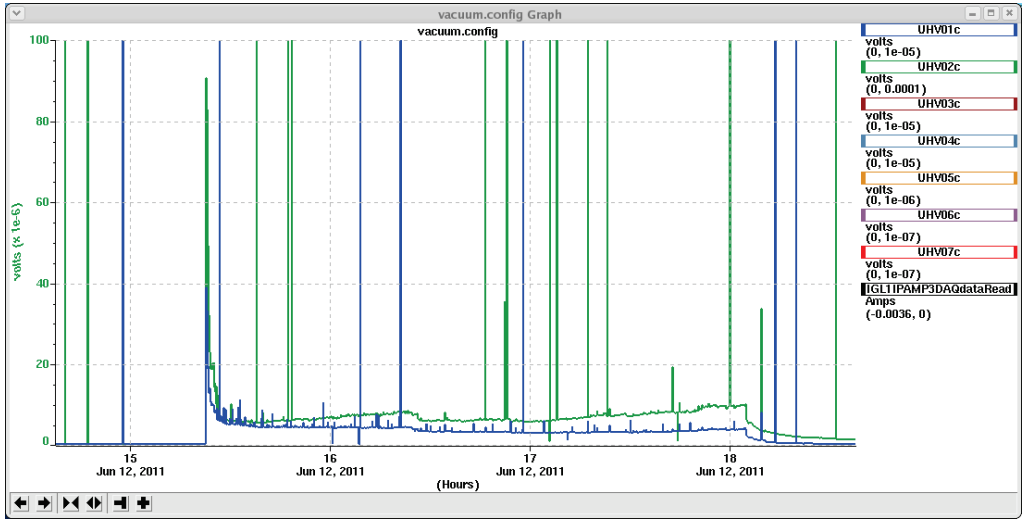
QE scan after event with 440 nm (850 micron spot)



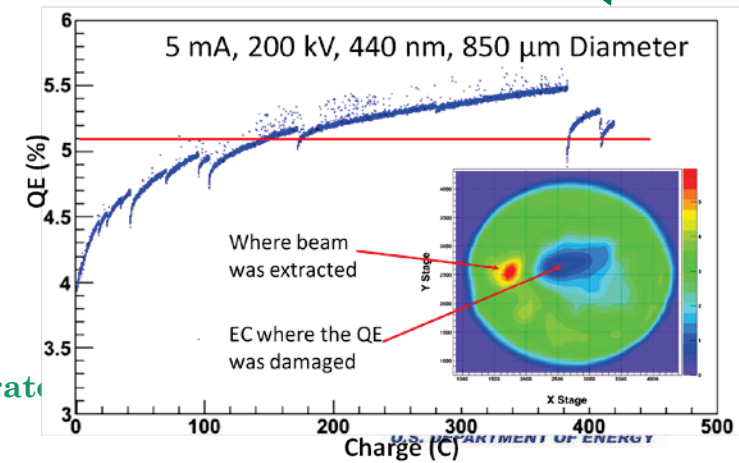
A power glitch caused some beam steering magnets to reset causing the electron beam to scrape a portion of the beam pipe. The high voltage and laser were not affected which resulted in 3 mA beam being extracted from the cathode in 5x10^{-10} Torr environment for ~2hours

Went back to running at 5 mA at a new spot, and the QE just kept going up…..

Is it laser heating or some kind of photochemistry?

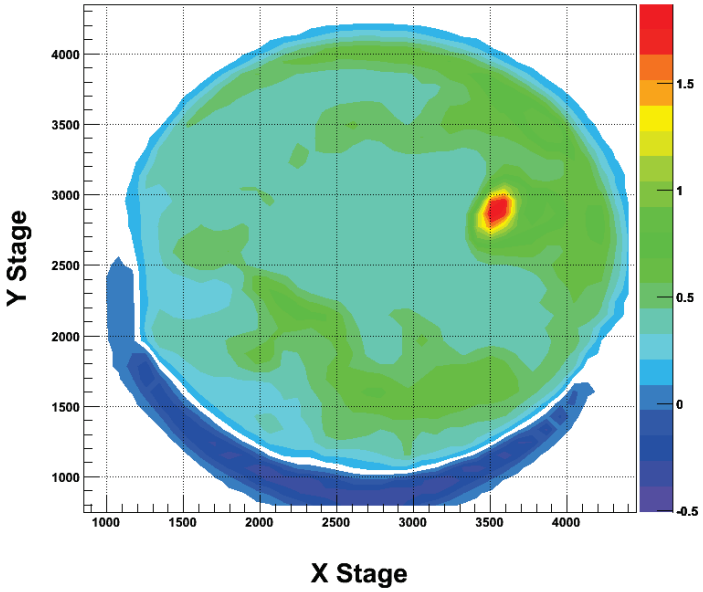


Vacuum rise from beam into bellows around 100x increase in vacuum level

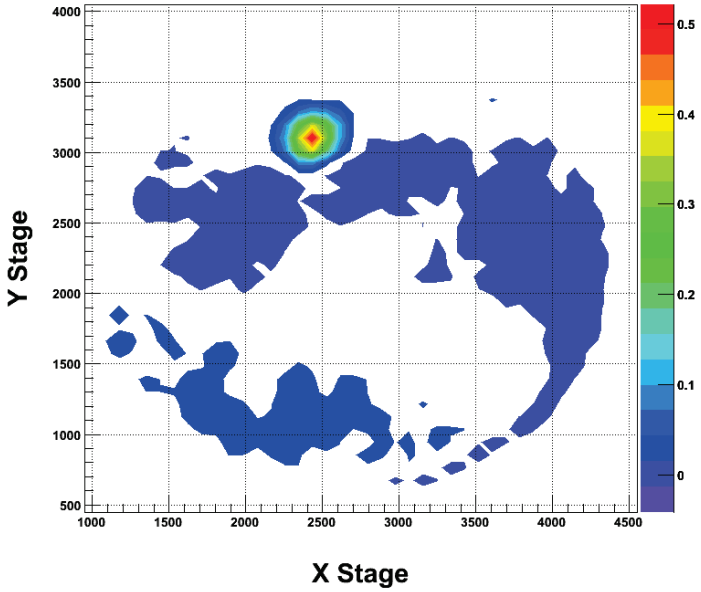


Laser heating

QE difference after heating 3500/2800 for 12 hours with 440 nm and 211 mW



QE difference after heating 2450/3100 for 2 hours with 532 nm and 672 mW

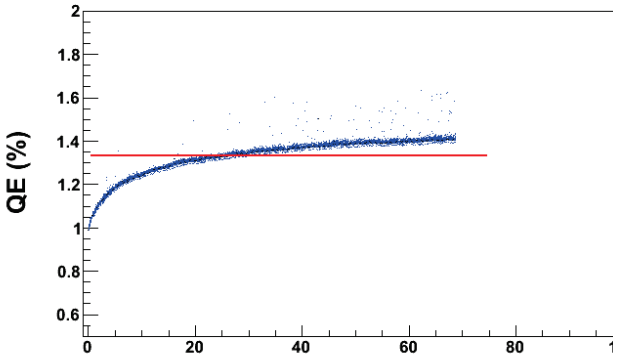


- **The QE increases without making beam – just illumination with light. Is the stoichiometry of the photocathode improving locally?**

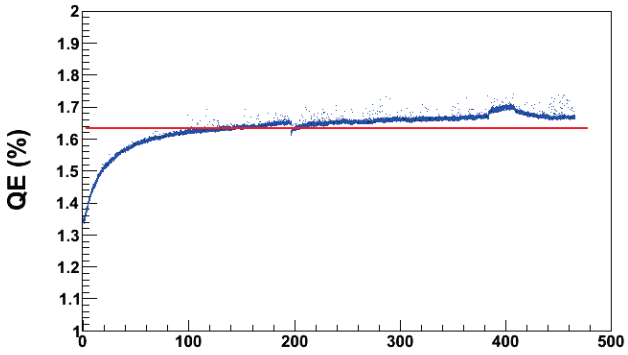
- **Running the beam into the bellows seems to have improved the cathode , outside of the EC.**
  - **Unclear if due to sputtering away low K surface layer**
  - **Or due to surface interactions with gases in the 'high' vacuum run**

532 nm, redo, at 200 kV, 350 µm spot

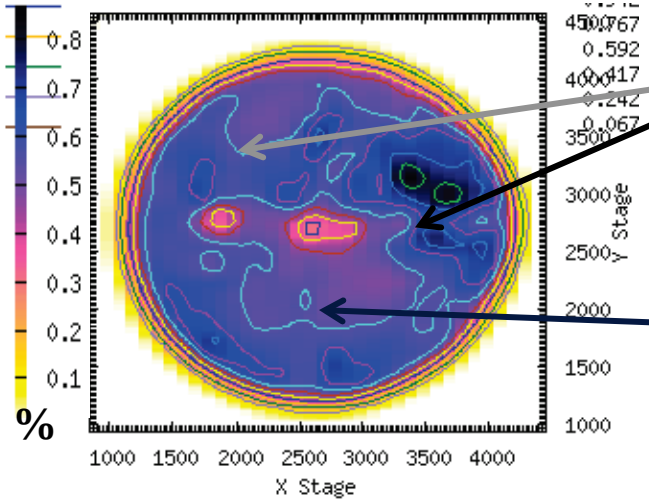
- **Entire surface (other than QE hole at center) has higher QE than before running 440 nm and the vacuum event.**
- **QE near run locations dramatically higher than before**



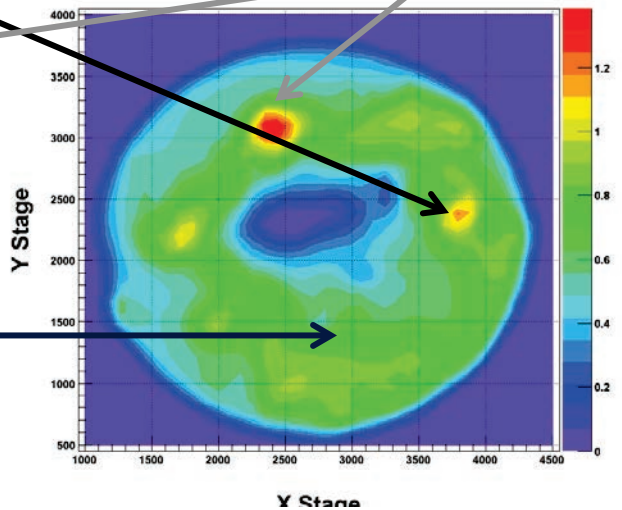
3.0 mA Run
Before 0.7%
After 1.3%



5.0 mA run (also heated at this location)
Before 0.5%
After 1.4%

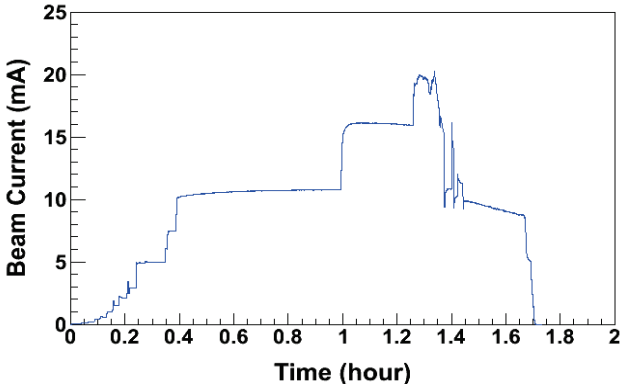


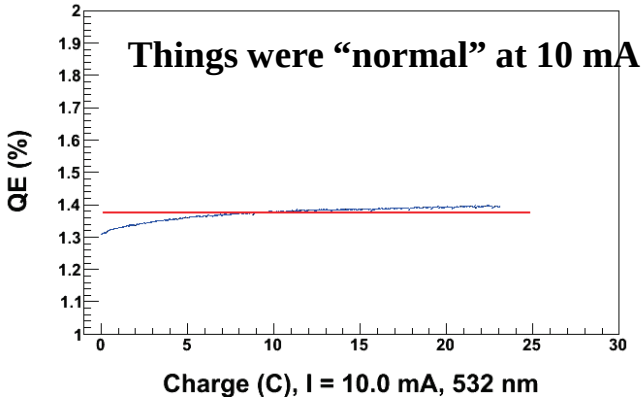
Location of no beam, ever
Before 0.5%
After 0.8%

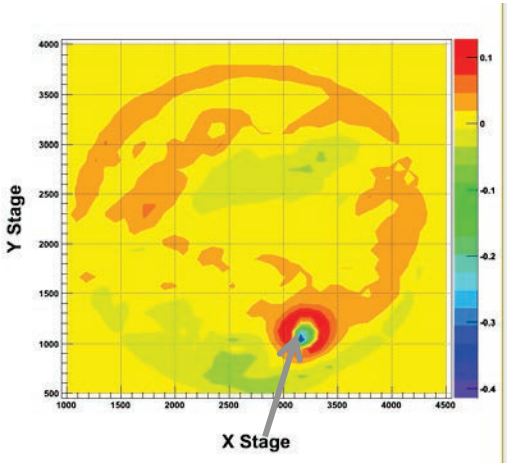


More 532 nm lifetimes

- **Decided to run maximum beam possible at 100 kV**
  - **Limited by laser power and possible beam dump heating**

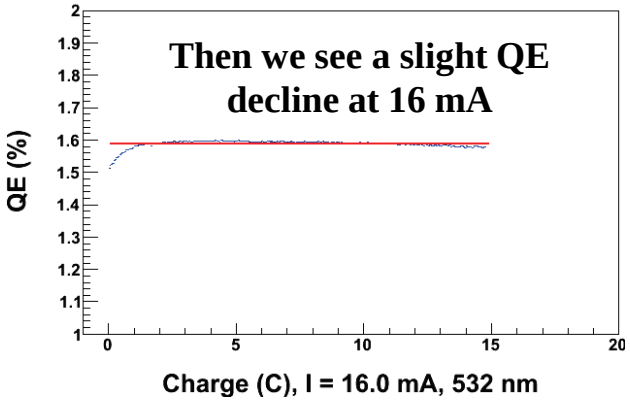


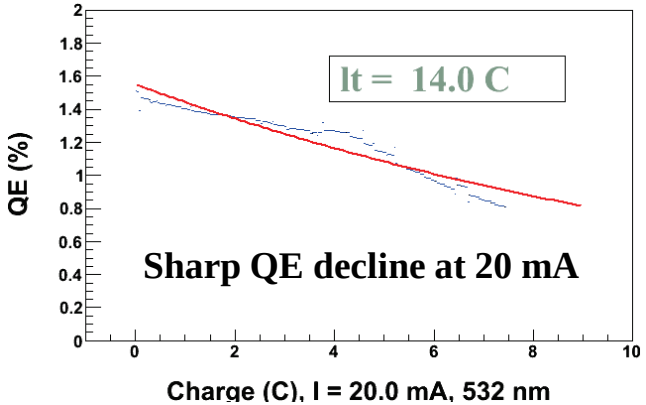




QE Change before and after the run.

Center of run location lost QE, surroundings gained.

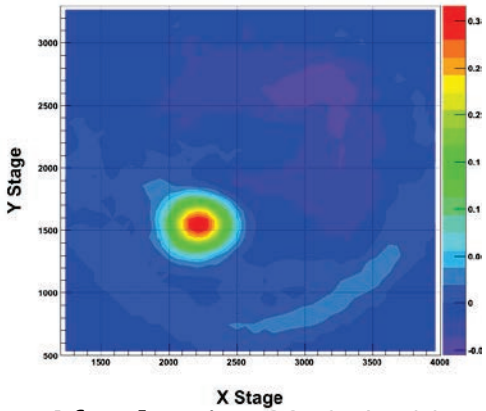




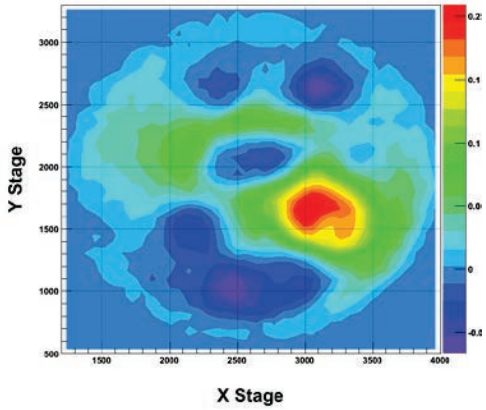
Earlier, we saw laser heating seemed to help, but now it seems it only helps up to certain laser levels.

More laser heating?

If it is really laser heating, then let's decrease the power density by increasing the spot size and first watch for QE decline from illuminating a spot before running beam with 800 μm spot, 200 kV.

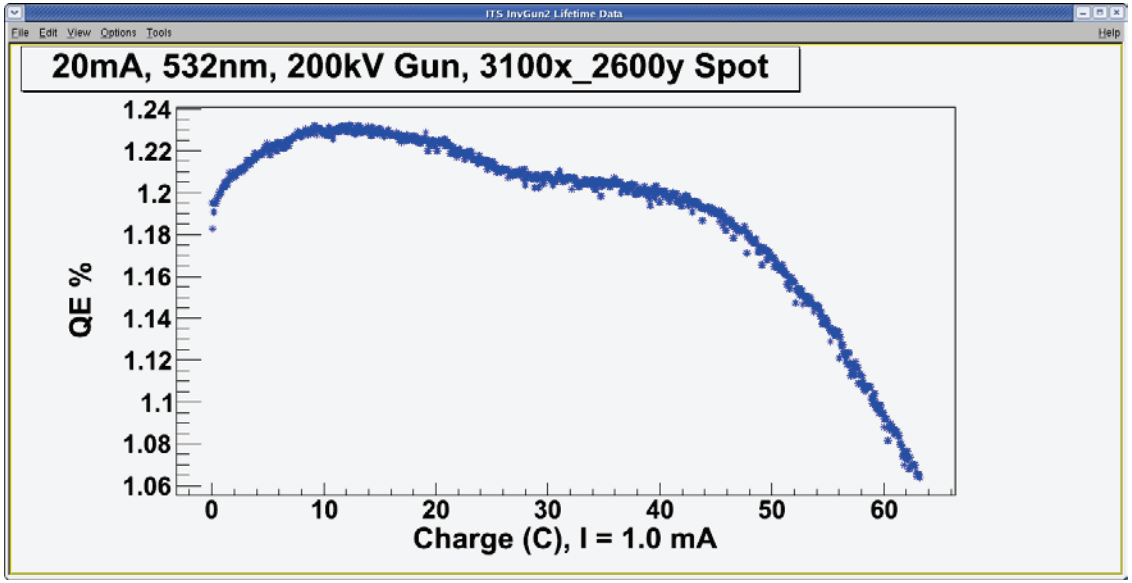


After heating 2250x/1500y with ~4 W for 30 mins.



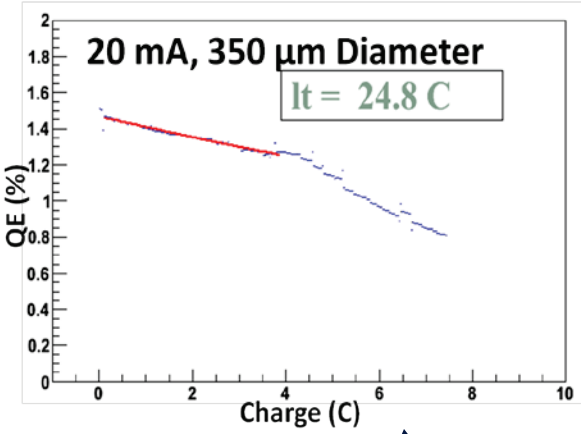
After heating 3200x/1500y with ~4 W for 1.5 hr.

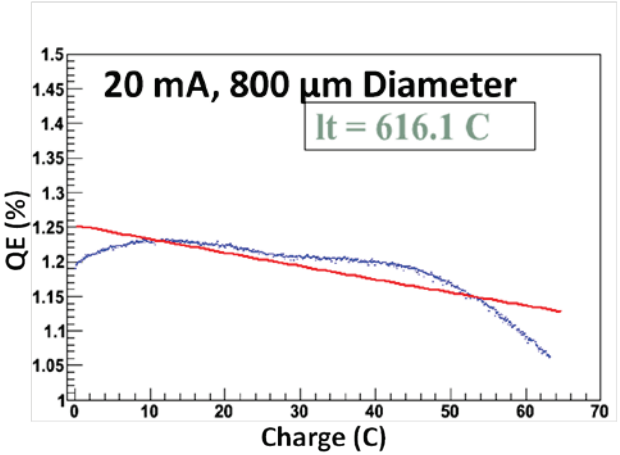
And then run…



Needed laser power near 4.5W to get beam current up to 20 mA.
Beam shape was very large and the radiation/vacuum along the beam pipe was larger than expected.

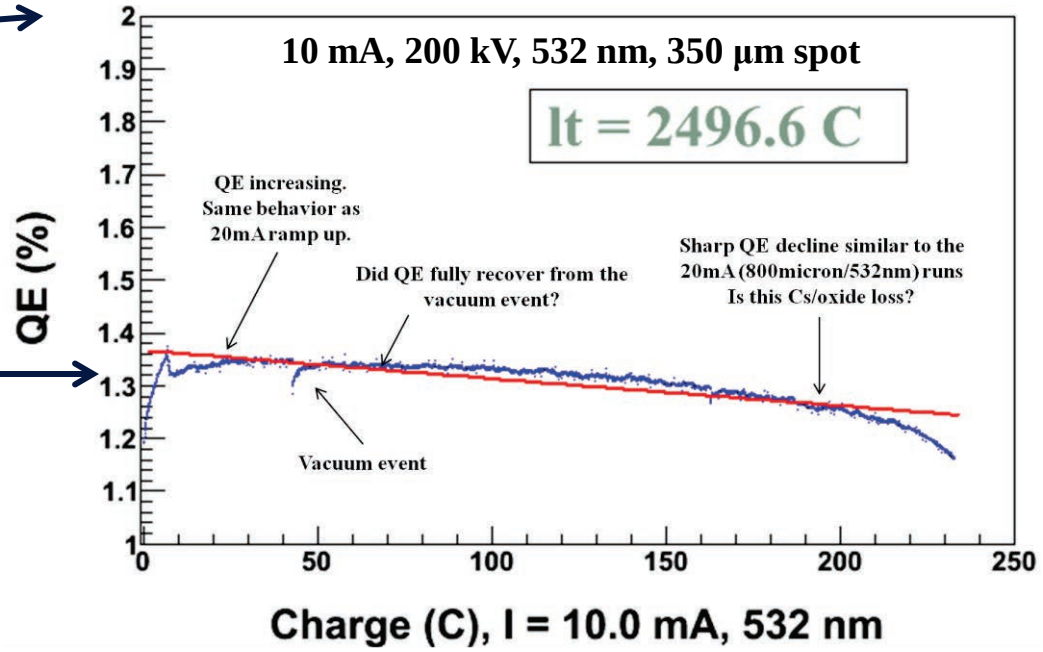
Spot size side by side





At 100 kV, the spot size increased roughly by a factor of 5, yet the lifetime went up by a factor of 20 or more, indicating that the decreased laser power density on the cathode increased lifetime.

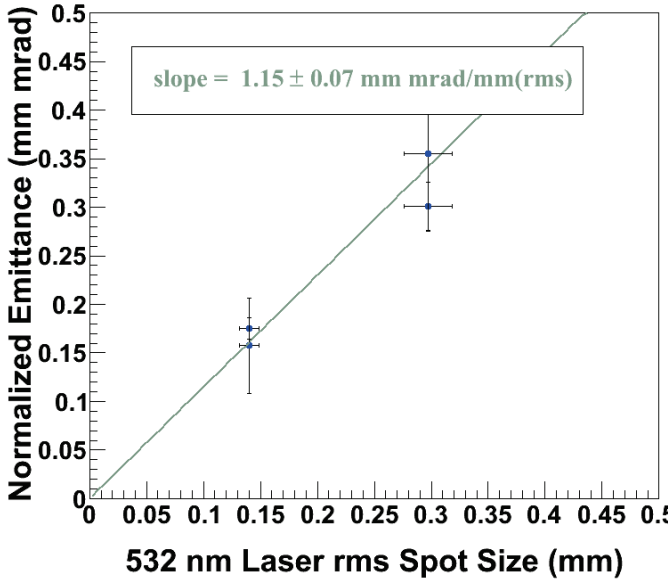
Even at longer runs, the QE decay now (after the major vacuum event) is much slower than GaAs

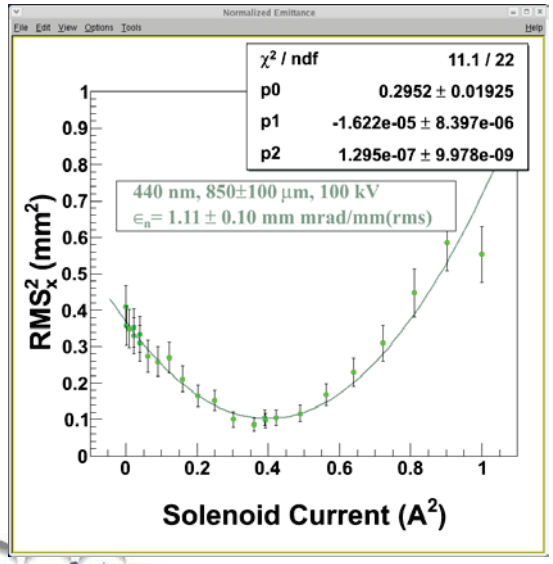


Emittance work

Done via solenoid scan technique at 100 and 200 kV, and 3 μA of beam.

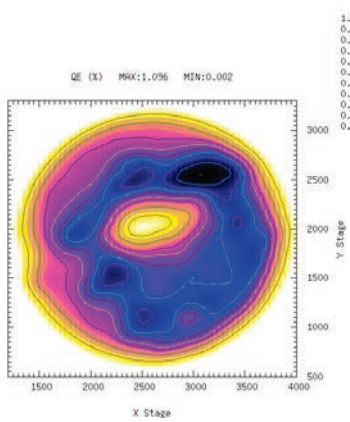
Summary of Emittance Measurements			
Laser Wavelength (nm)	Laser FWHM (um)	HV (kV)	Normalized Emittance (mm mrad/mm(rms)
440	850	100	1.11 +/- 0.10
440	850	200	0.97 +/- 0.18
532	330	100	1.25 +/- 0.08
532	330	200	1.12 +/- 0.35
532	700	100	1.01 +/- 0.08
532	700	200	1.19 +/- 0.27



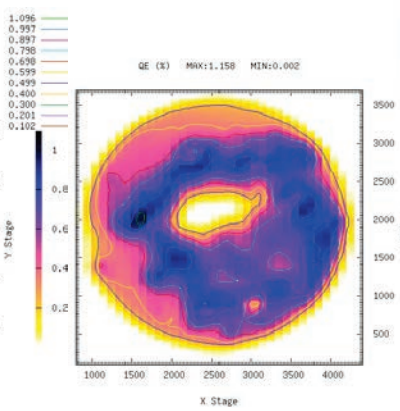


- **Emittance was roughly twice that of previous measurements made at Cornell on a similar cathode .**
- **The increase can partially be attributed to the high surface roughness of the JLab/BNL photocathode (coming up).**

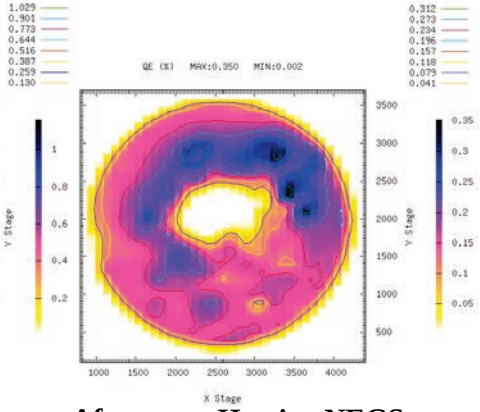
How to kill a cathode….



Before Heating NEGS

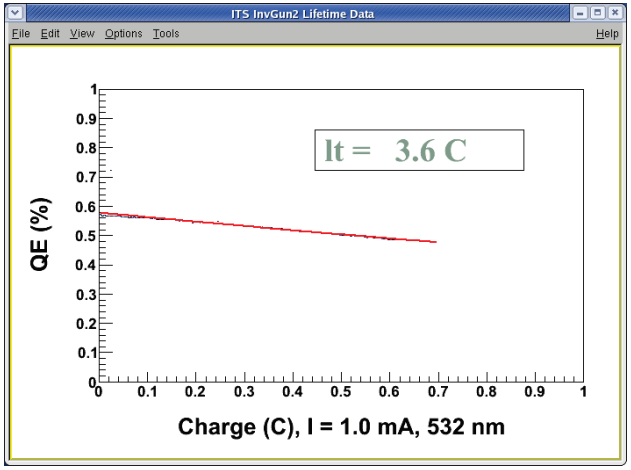


After Heating NEGS:
5.0A (4 hr), 9.3 A (3hr), 8.0 A (0.5 hr)
8E-10 Torr (mostly H_2)



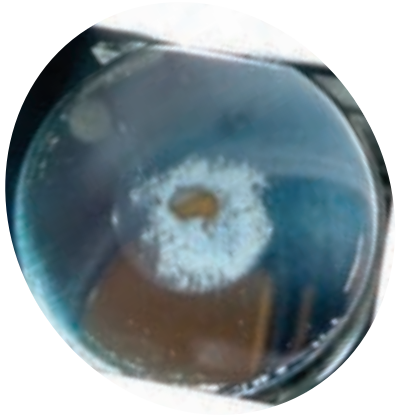
After more Heating NEGS:
5.0A (4 hr), 9.3 A (3 hr),
8.0 A (17 hr), 0.0A (6 hr)
Ion pump =0.4 nA, Ext. Gauge off

Heated the NEGs in the hopes of running beam in a high H_2 environment.



Very bad lifetime, but unknown if due to vacuum or heat. The entire gun chamber became warm to the touch, including the HV cable, indicating that the photocathode heated, though to an unknown amount.

Also, QE of entire cathode dropped by 1/3.



Photograph of puck right after pulling into the prep chamber

Try (but fail) to recover with Cs..

- **Moved puck into prep chamber (used for activation of GaAs) to add Cs.**
- **Heated puck up to 120 C - photocurrent 9-10 pA during ramp up.**
- **130 C – photocurrent drop to 5 pA.**

Started Adding Cesium
Immediately the photocurrent went up and then fell. After this and for the rest of the Cesiation, no observable photocurrent at 532nm.
Saw a modest change in photocurrent with white light. Heated Cesium strip for ~1 hr.

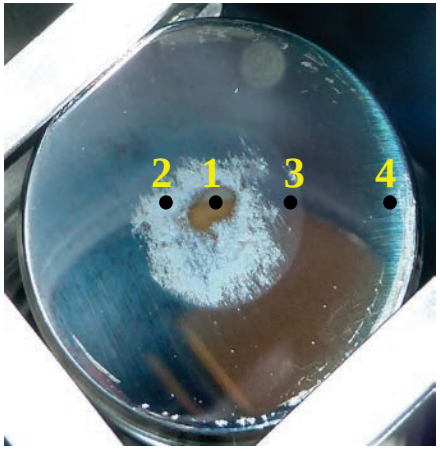
Time	Cs Strip Current (A/C) A	Puck Temp ˚C	Ion Pump Current (nA)	White light Photocurrent (pA)
15:39	4.5	133	500	4
15:44	4.5	133	600	3
15:54	4.5	134	700	2.1
15:57	4.6	134	780	1.5
16:03	4.6	134	830	1.5
16:13	4.6	134	960	1.5
16:25	4.6	134	1000	.7

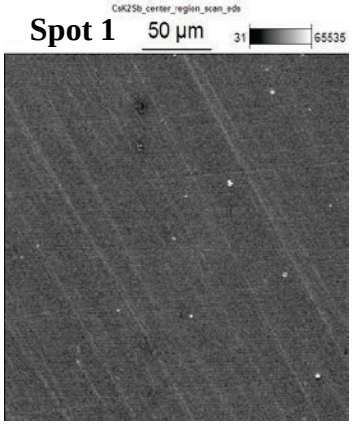
Turned off Cs, moved out of the way, measured photocurrent, and moved puck off the heater to a puck transfer manipulator to cool.

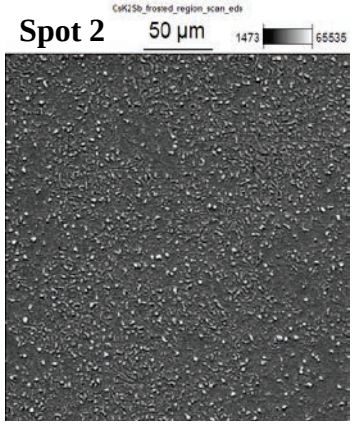
	Photocurrent before heating (pA)	Photocurrent after cesium hot puck (pA)
White light	n/a	28
410 nm	130	7
530 nm	13	0

SEM the dead photocathode

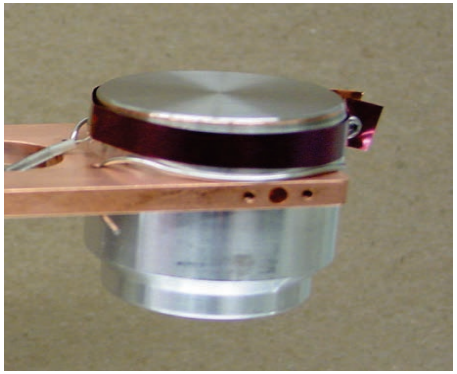
Taken after all measurements in the DC gun.
Transferred to SEM via argon bag.

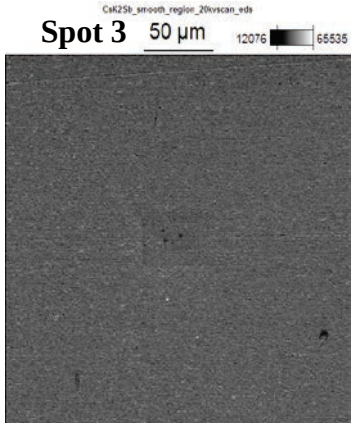






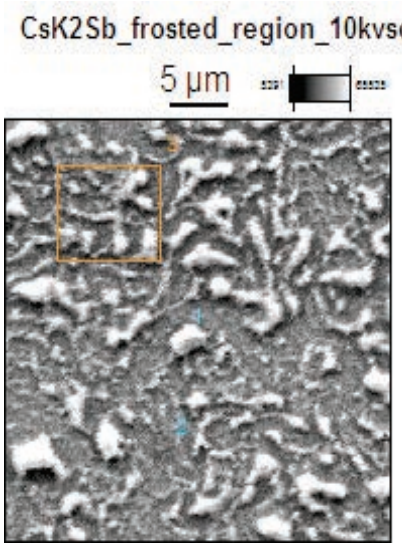
Images of the spots at 400x with 20 keV electrons.





SEM results (cont.)

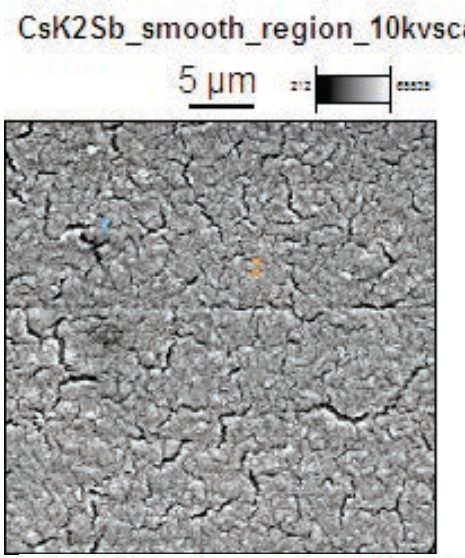
Images of the spots at 3000x with 10 keV electrons



Spot 2

The frosted to the eye region is made of islands.

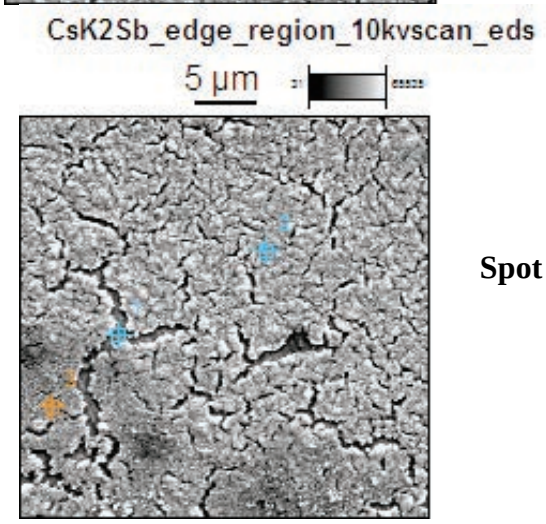
Islands are made of of Cs, K, Sb, O, and C . The areas between the flakes are mostly SS with some Sb.



Spot 3

The "smooth" regions show cracks in the film.

Cracks are exposed SS surface.



Spot 4

Summary and Future Work

Summary

- **Initially promising results at 440 nm**
- **Vacuum event modified surface to drastically improve 532 nm performance**
- **Local heating can either increase/decrease lifetime**
- **Emittance higher than other measurements**
- **Global heating very, very bad for cathode**
- **Recovery of QE by addition of Cs unsuccessful**
- **SEM shows very rough surface**

Future

- **Obtain new cathode with proper stoichiometry**
- **Measure emittance as soon as put in Jlab gun**
- **Lifetime in bad vacuum, without heating puck**
- **Lifetime at higher current (up to 30 mA supply)**

Take away message….

Unlike GaAs, K_2CsSb can take a beating and keep on ticking….

The End

- **Any questions?**
- **Comments?**