Operation of CEBAF photoguns at average beam current > 1 mA

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Can we improve charge lifetime by merely increasing the laser spot size? (distribute ion damage over larger area)

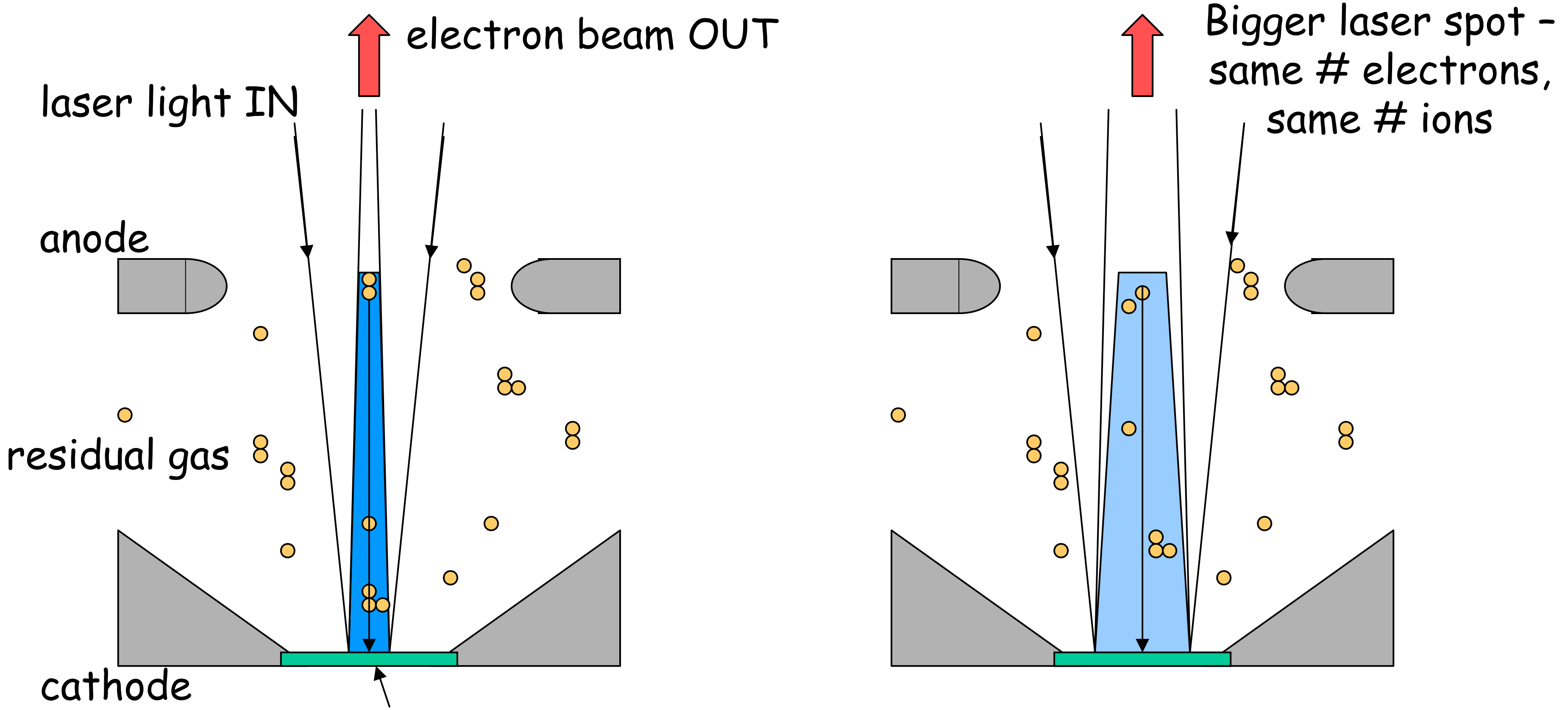
How relevant is CEBAF experience at 200 uA ave current and laser spot size ~ 500 um for operation at mA beam current?

Important questions for high current (> 1mA) photoinjectors at FELs, ERLs and proposed NP facilities like ELIC and eRHIC

Ion Backbombardment Limits Photocathode Lifetime

(Best Solution – Improve Vacuum, but this is not easy)

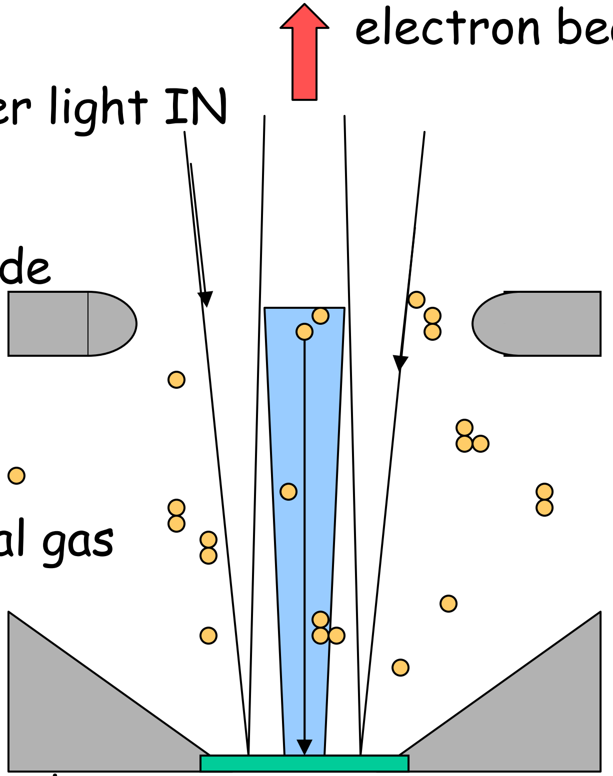
Can increasing the laser spot size improve charge lifetime?



But QE at (x_i,y_i) degrades more slowly because ion damage distributed over larger area (?)

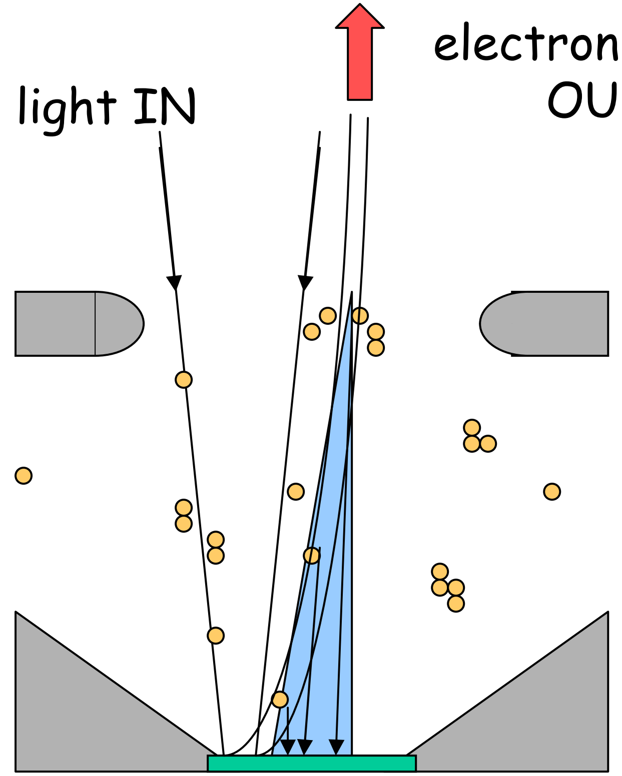
Where do ions go? Reality more complicated

High energy ions focused to electrostatic center



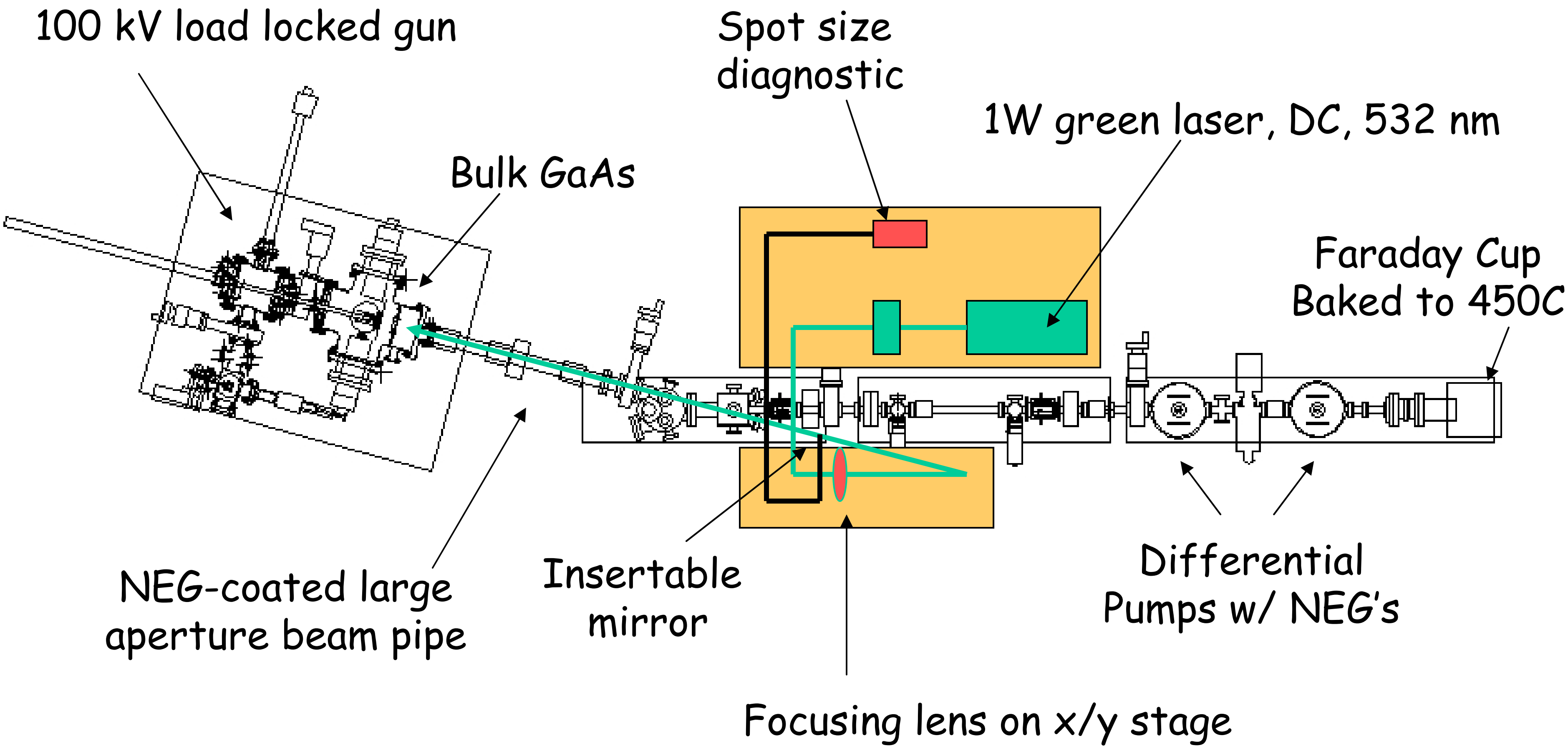
Which ions more problematic?

We don't run beam from electrostatic center

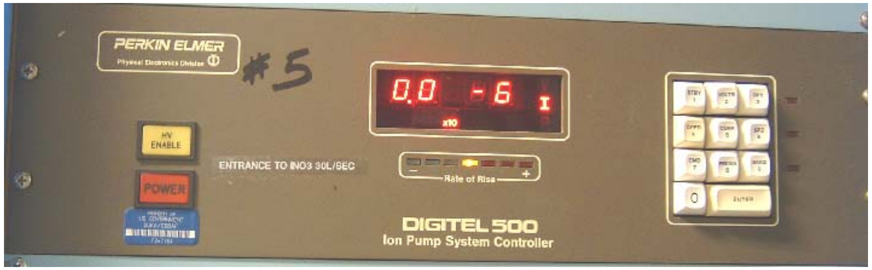


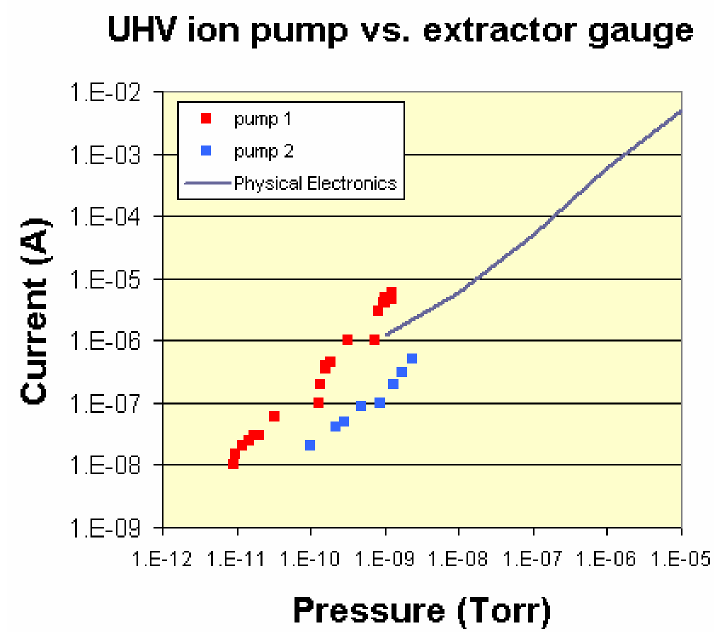
Ions create QE trough to electrostatic center

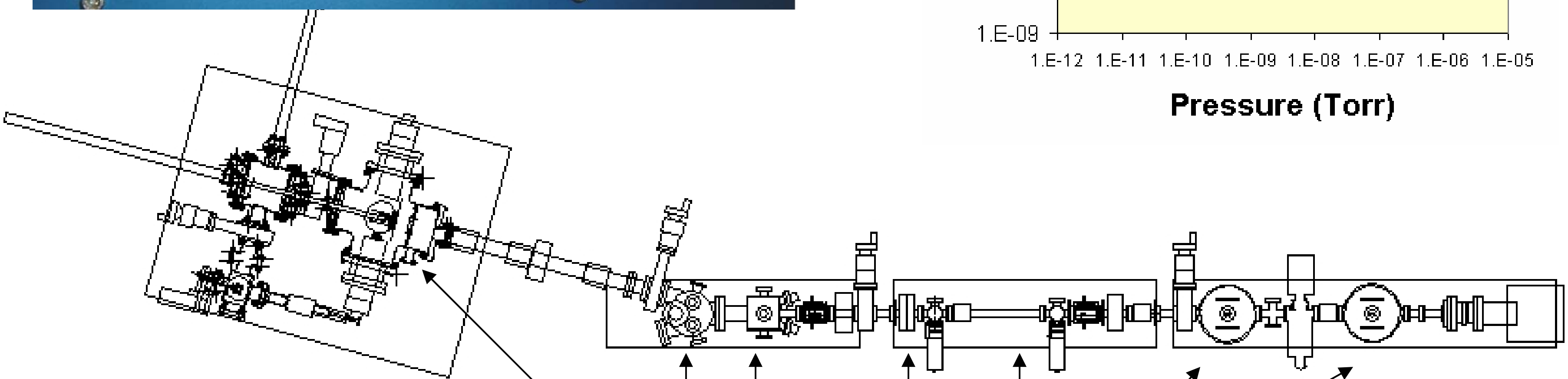
Experimental Setup



Sensitive Pressure Monitoring Along Beamline

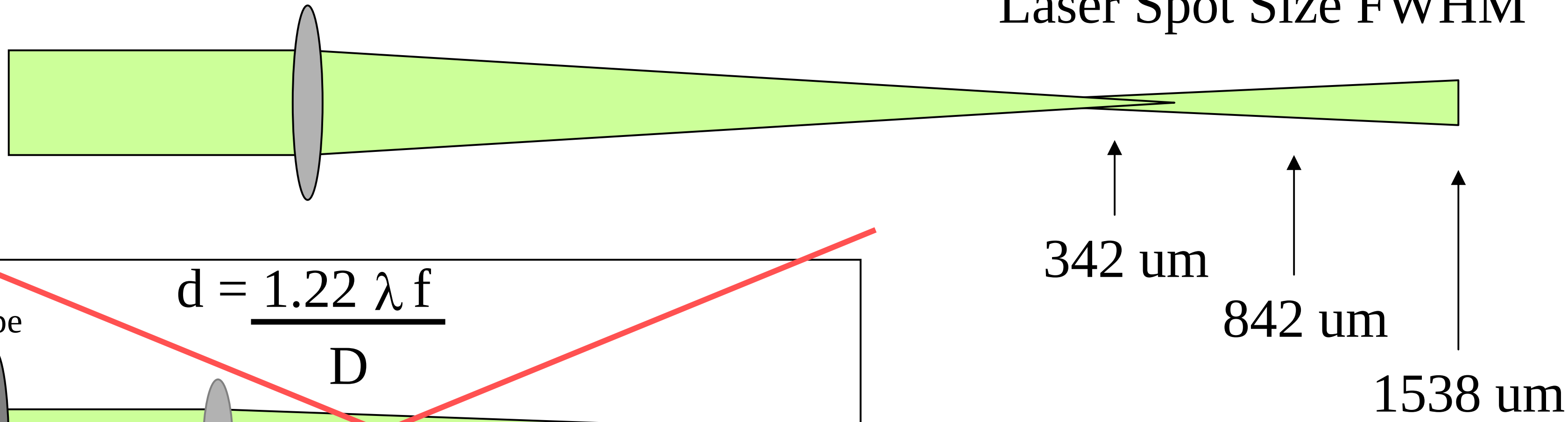


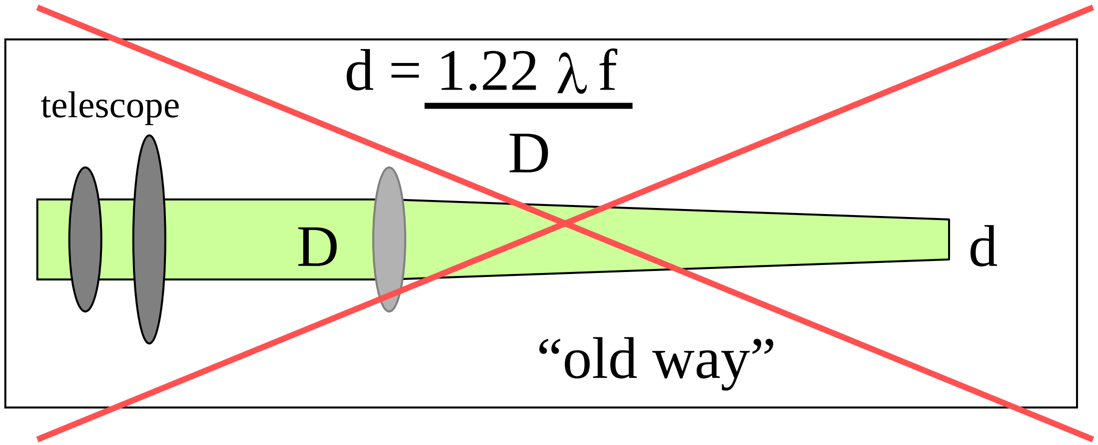


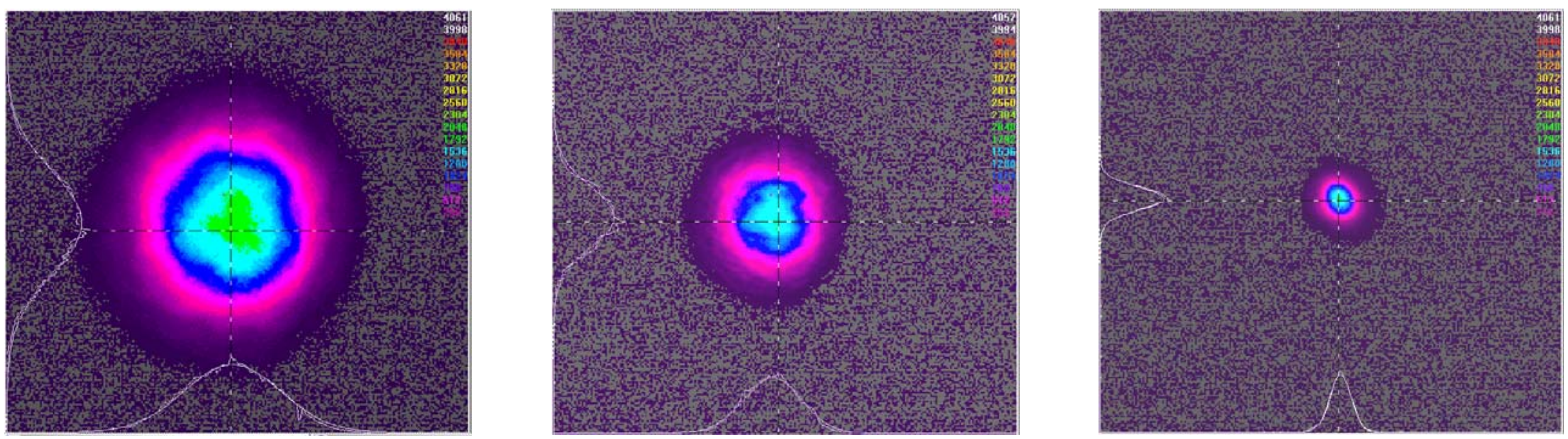


Ion Pump Locations

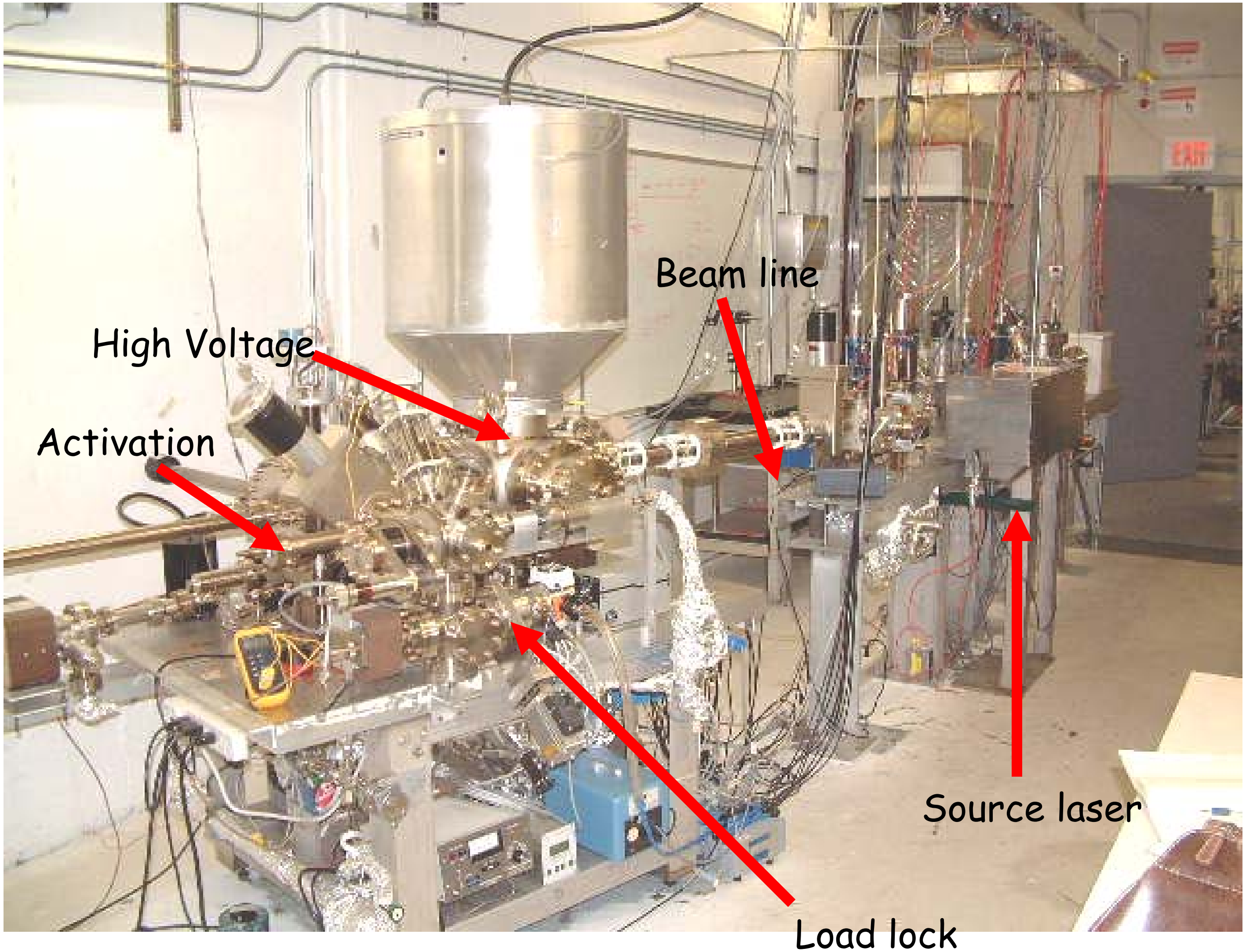
Laser Spot Size FWHM



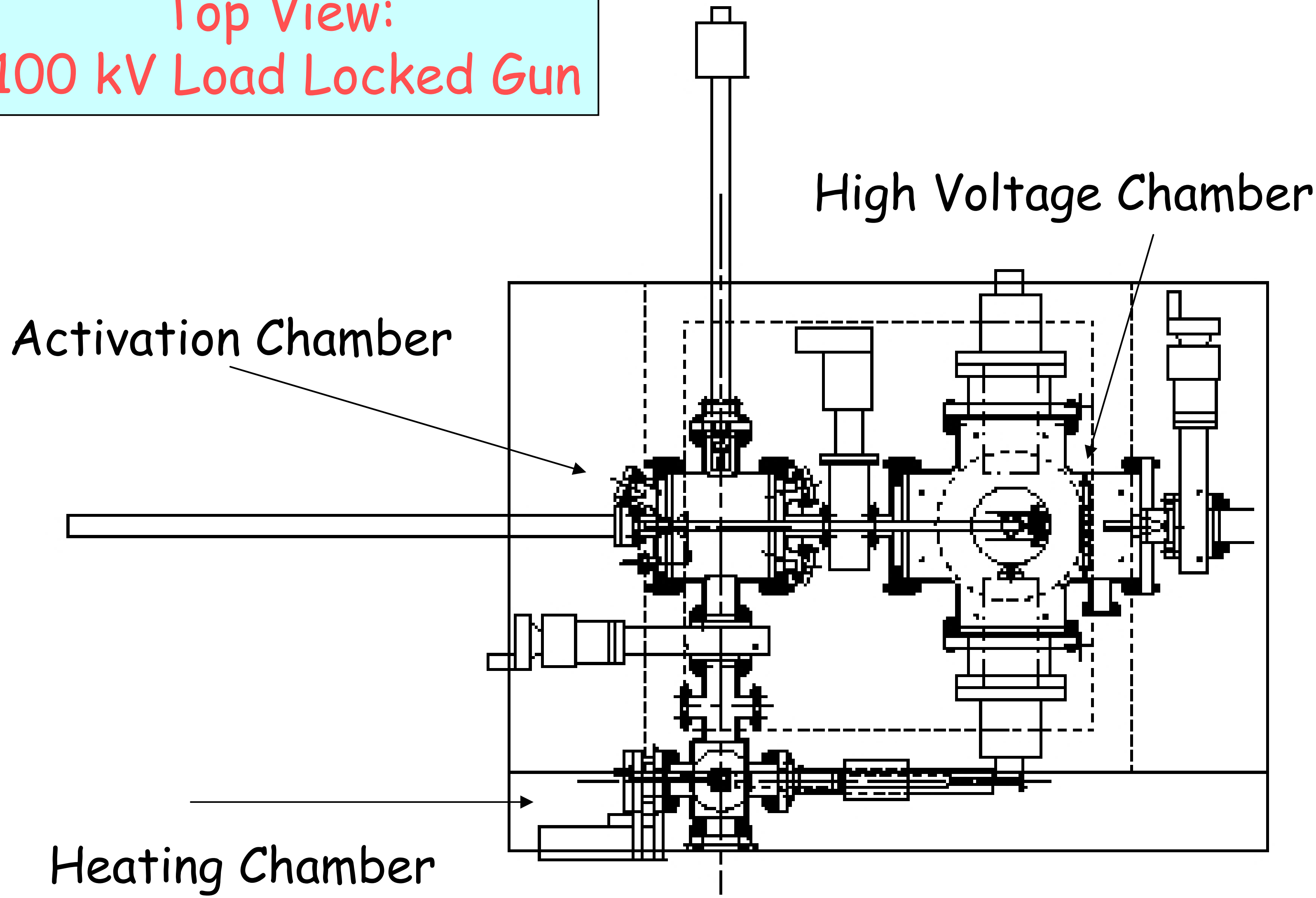




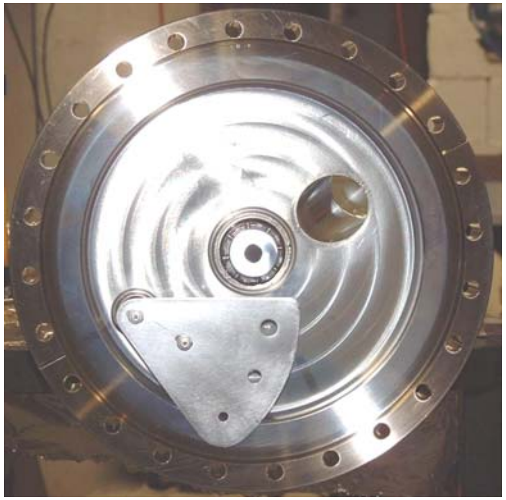
Spiricon CCD camera + razor blade stepper motor scans (not shown)


Beam line
High Voltage
Activation
Source laser
Load lock

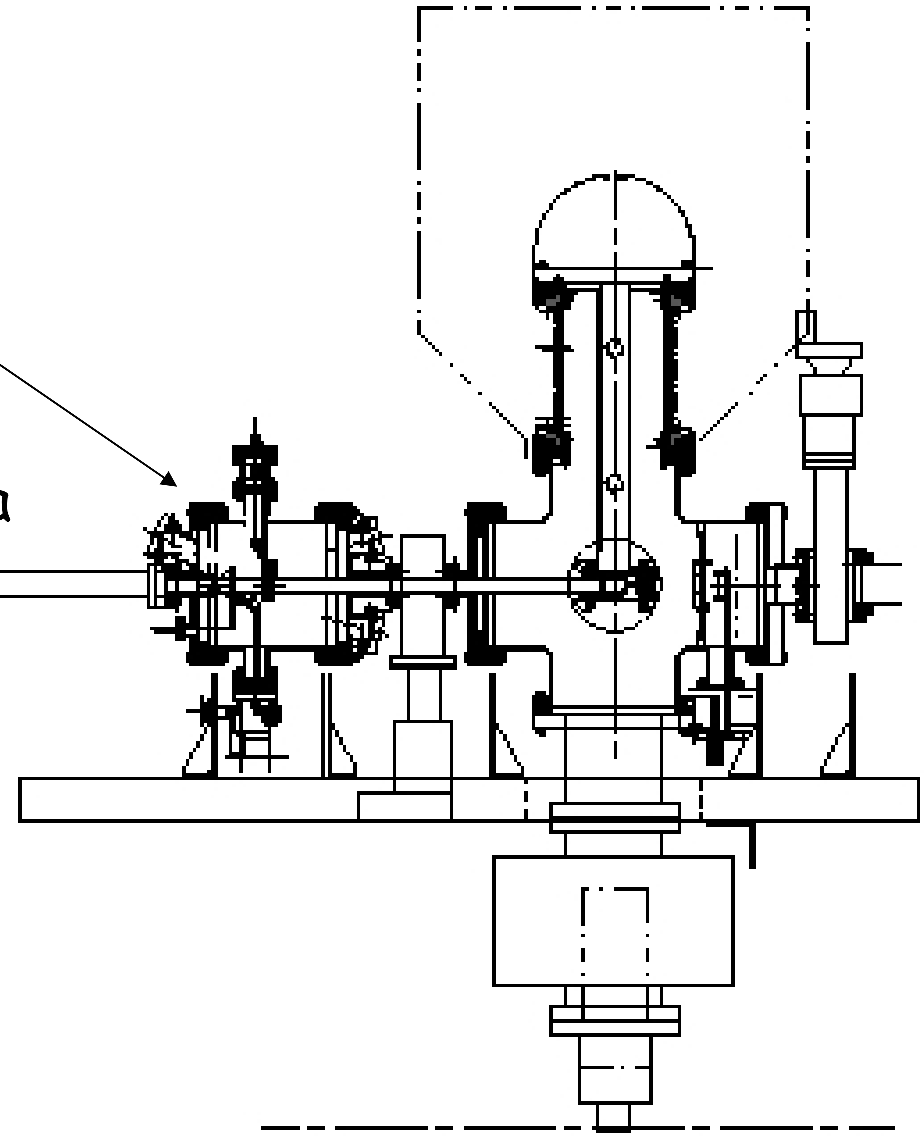
Top View: 100 kV Load Locked Gun



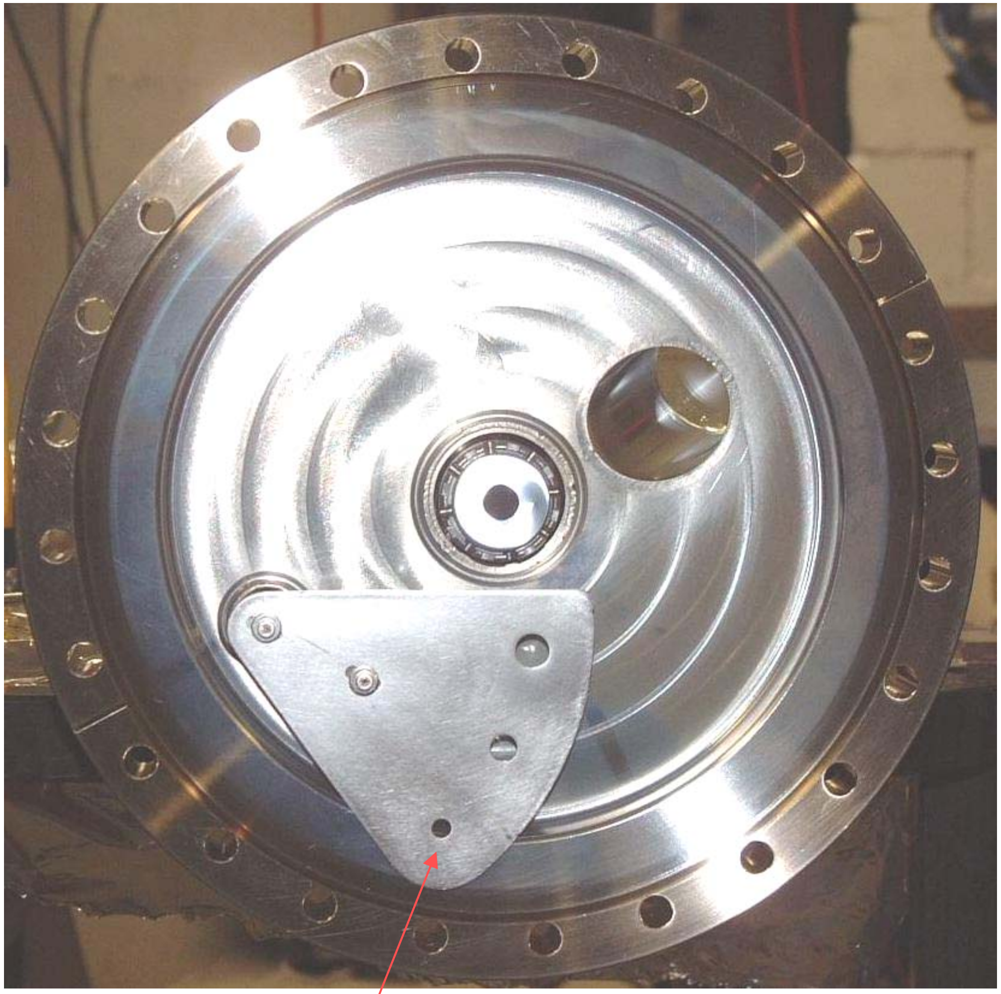
Side View: 100 kV Load Locked Gun



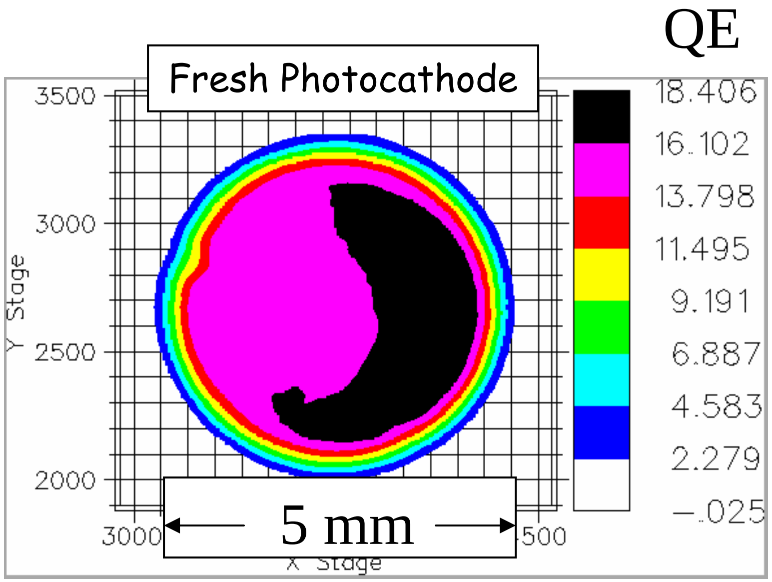
Mask to limit active area

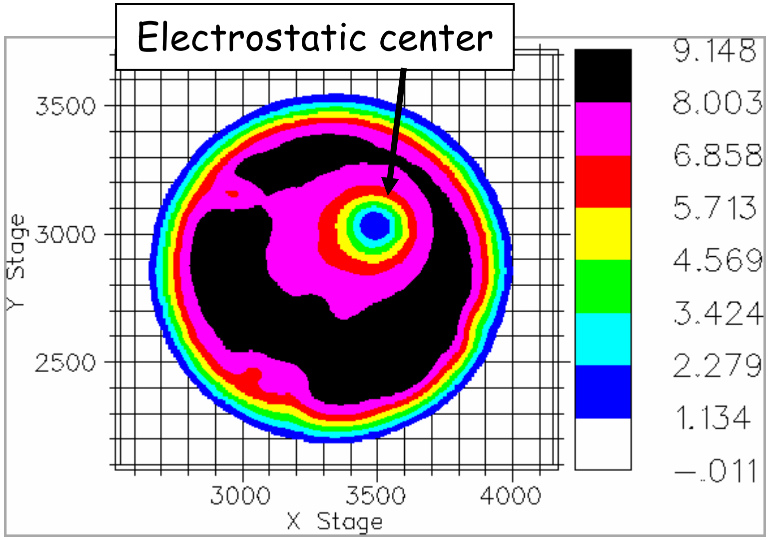


"QE Scan" using lens attached to stepper motor x/y stage



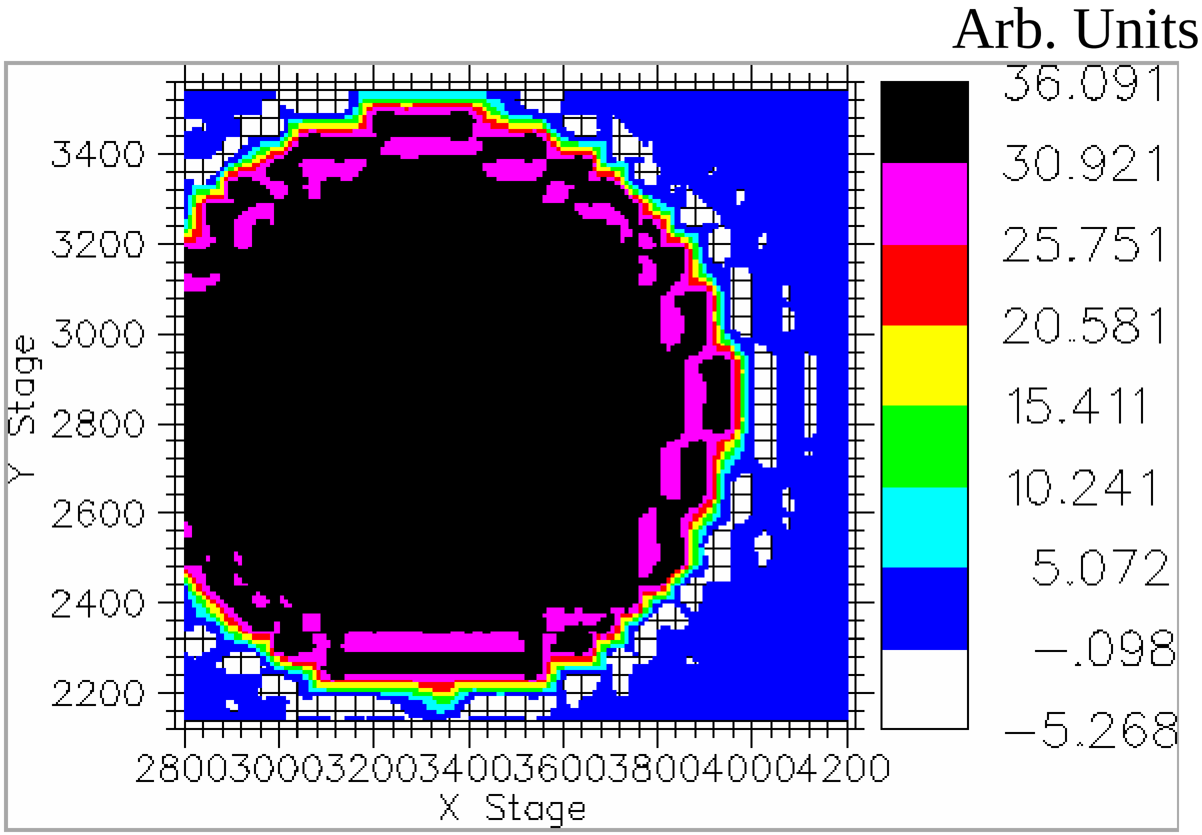
Used 5 mm hole throughout experiment





Is 5 mm active area well suited for gun geometry?

QE scan at 100 kV indicates beam from entire photocathode delivered to dump. Gun/beamline "acceptance" seems adequate



Experiment;

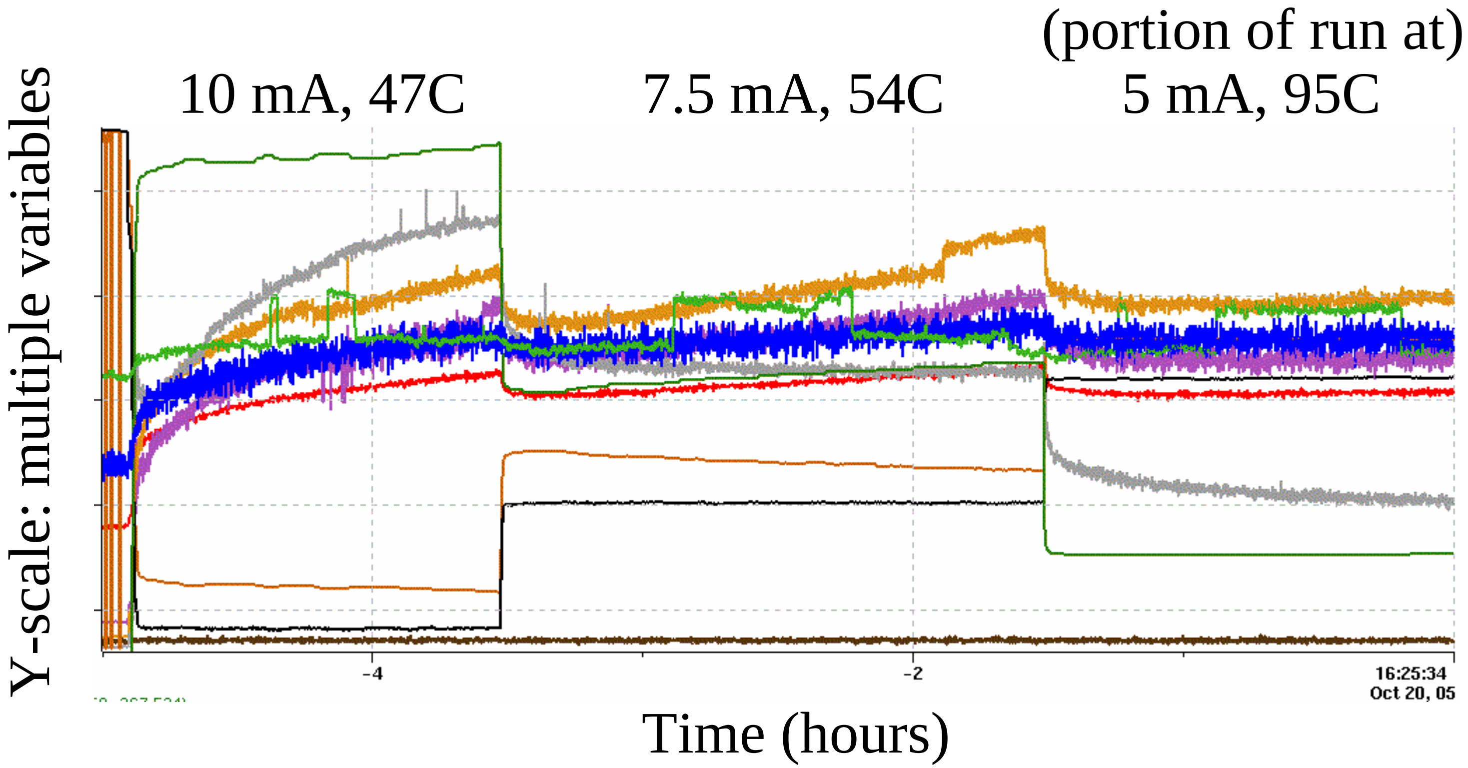
Measure 1/e charge lifetime using different laser spot sizes. Strive to keep other operating conditions constant (e.g., orbit, position of laser spot on photocathode, starting QE, etc).

Details:

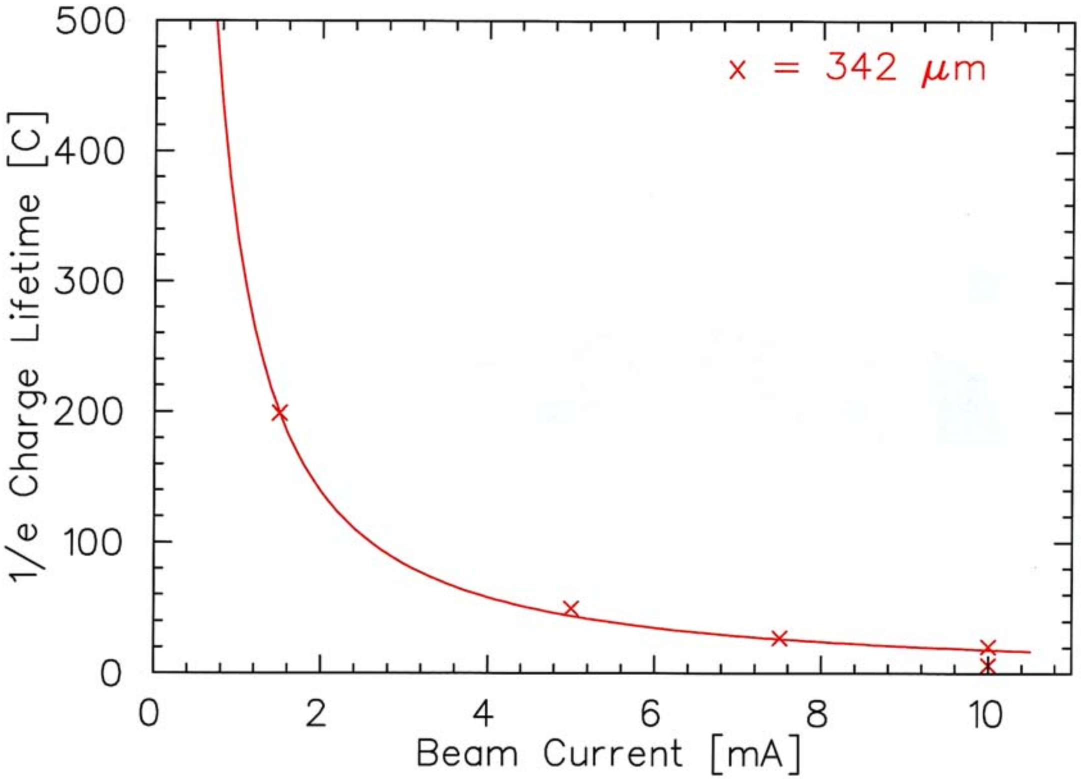
- Green light at 532 nm, DC Beam.
- Gaussian laser spots: runs at 342um, 842um and 1538um
- Bulk GaAs, initial max QE between 13 - 19%, 5 mm active area
- Gun vacuum w/o beam ~ 2x10^-11Torr
- Beam dump degassed at 450C
- Beam current constant via feedback loop to laser attenuator
- Record ion pump current, laser power "pick-off" monitor.
- Charge extracted during each run between 10 - 200 C
- Five activations, one photocathode, total charge extracted 1345 C
- Ion damage restoration, typ. heat at 575C for 24 hours

A "typical" set of runs: Record ion pump current at 7 beamline locations, laser power via "pickoff" detector, laser attenuator setting, beam current at dump.

$$\text{1/e Charge Lifetime} = \frac{\text{Charge Extracted}}{\ln(QE_i/QE_f)}$$



1/e Charge Lifetime versus Beam Current, 342 um laser spot

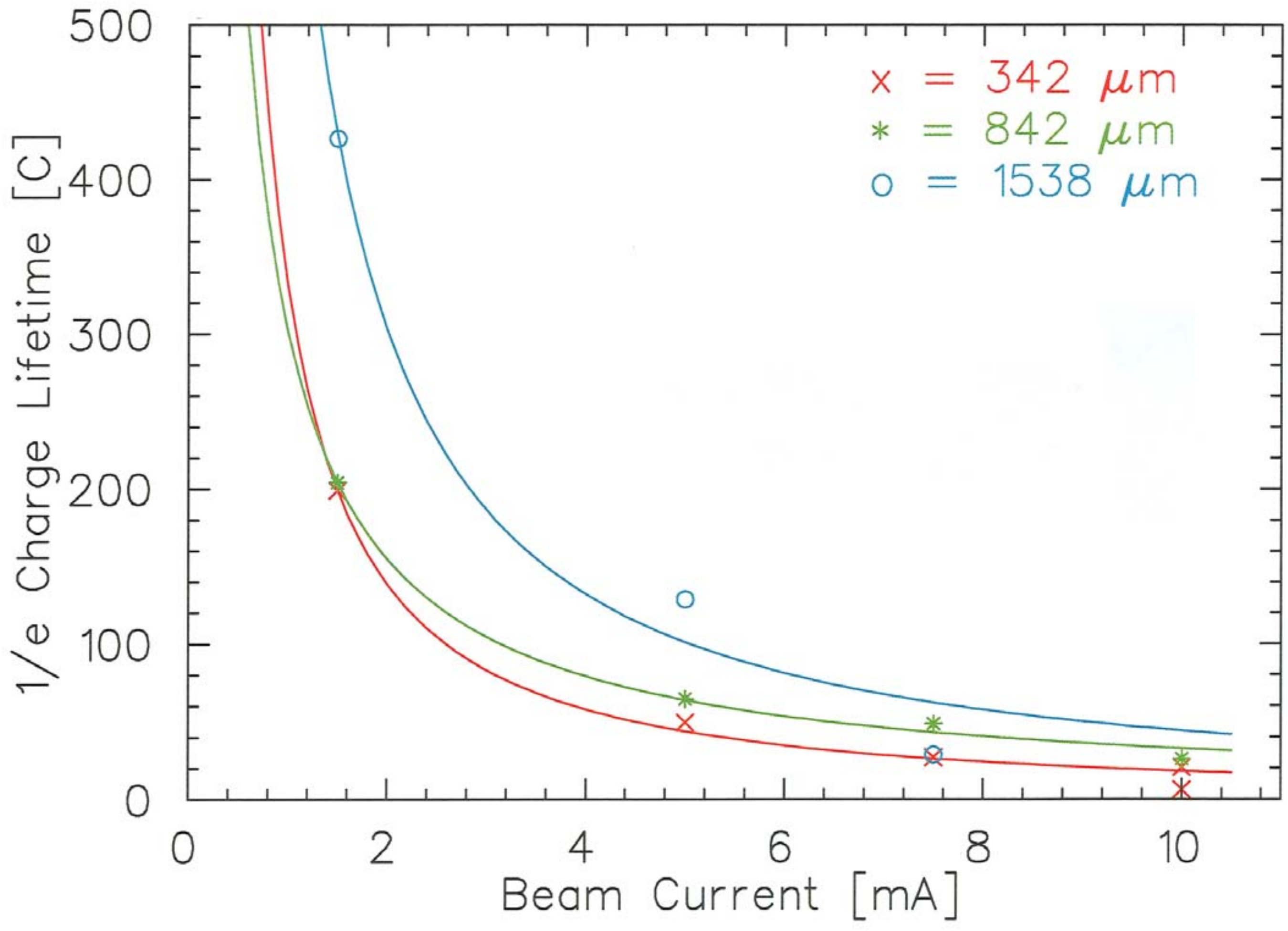


Fit = a / i^b
Why? Why not?
Lifetime scales as $1/i^b$ where i is beam current.
Here b = 1.256

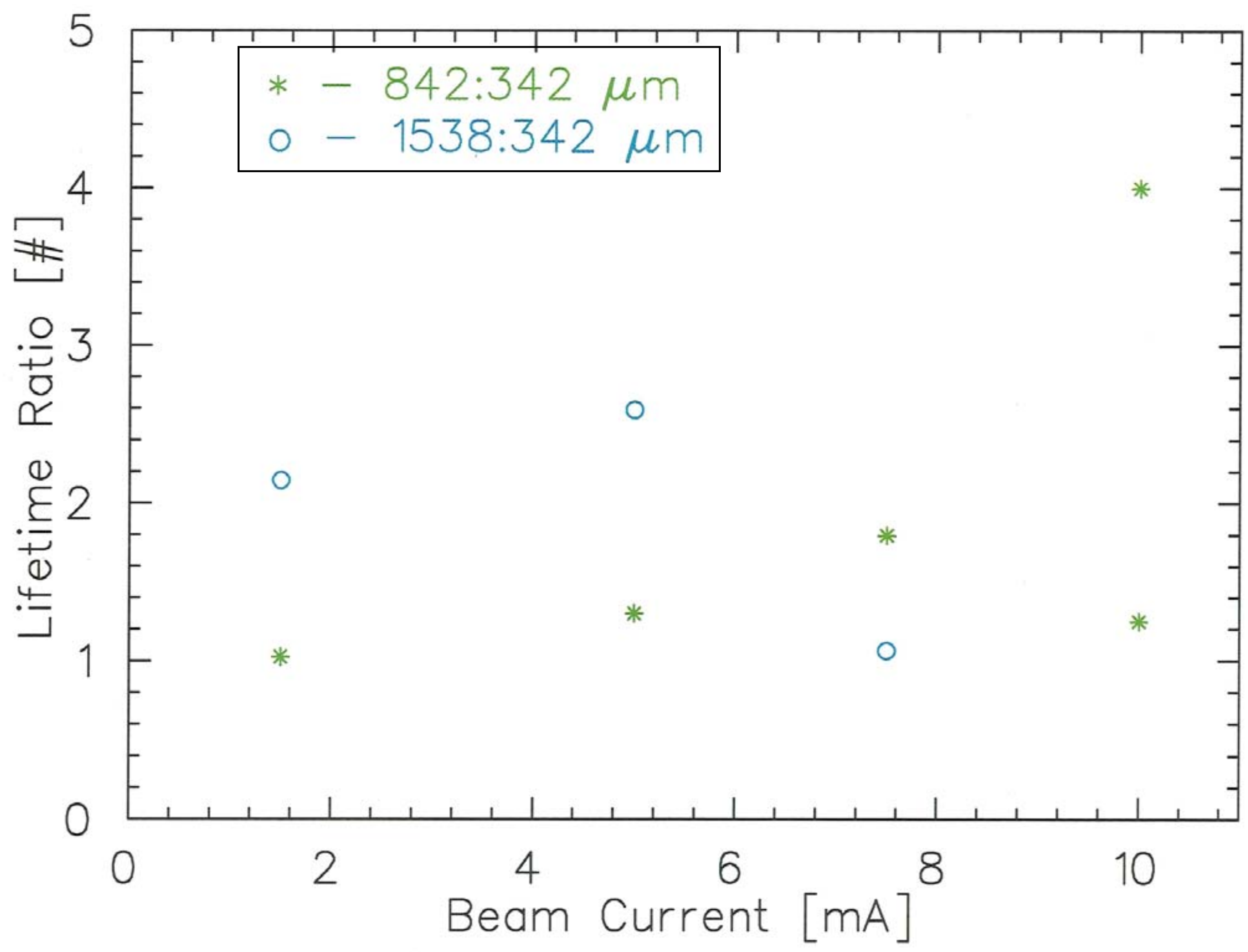
Later, we see b ranged from 0.2 to 1.3 for entire set of runs. More later.

Charge lifetime worse at high current. This makes sense - More electrons to ionize gas, and more gas to ionize (from beam dump and elsewhere).

1/e Charge Lifetime vs Beam Current: 342um, 842 um and 1538um



Very little, if any, lifetime enhancement with larger laser spots

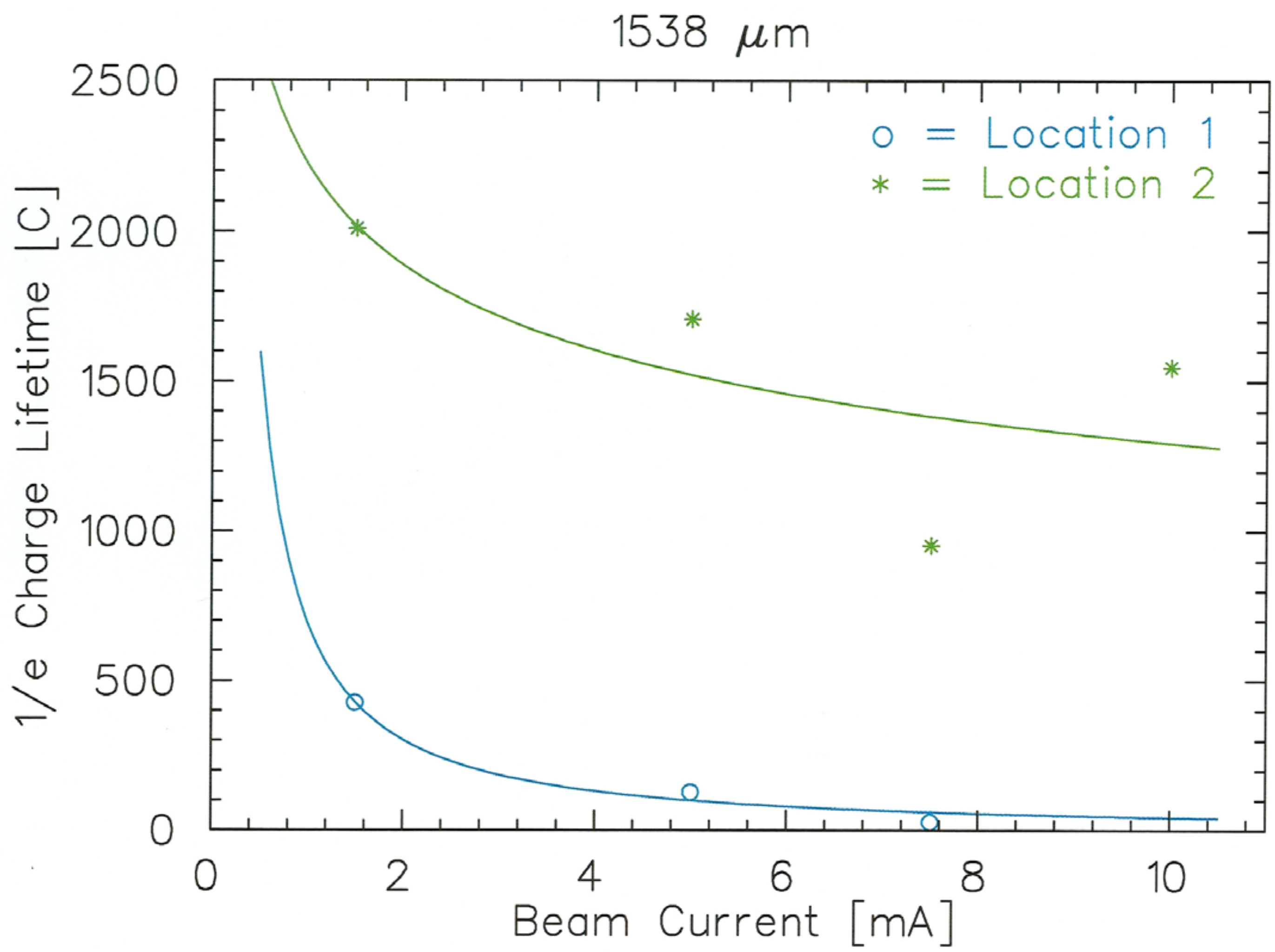


Expectation:

$$\left(\frac{1538}{342}\right)^2 = 20.2$$

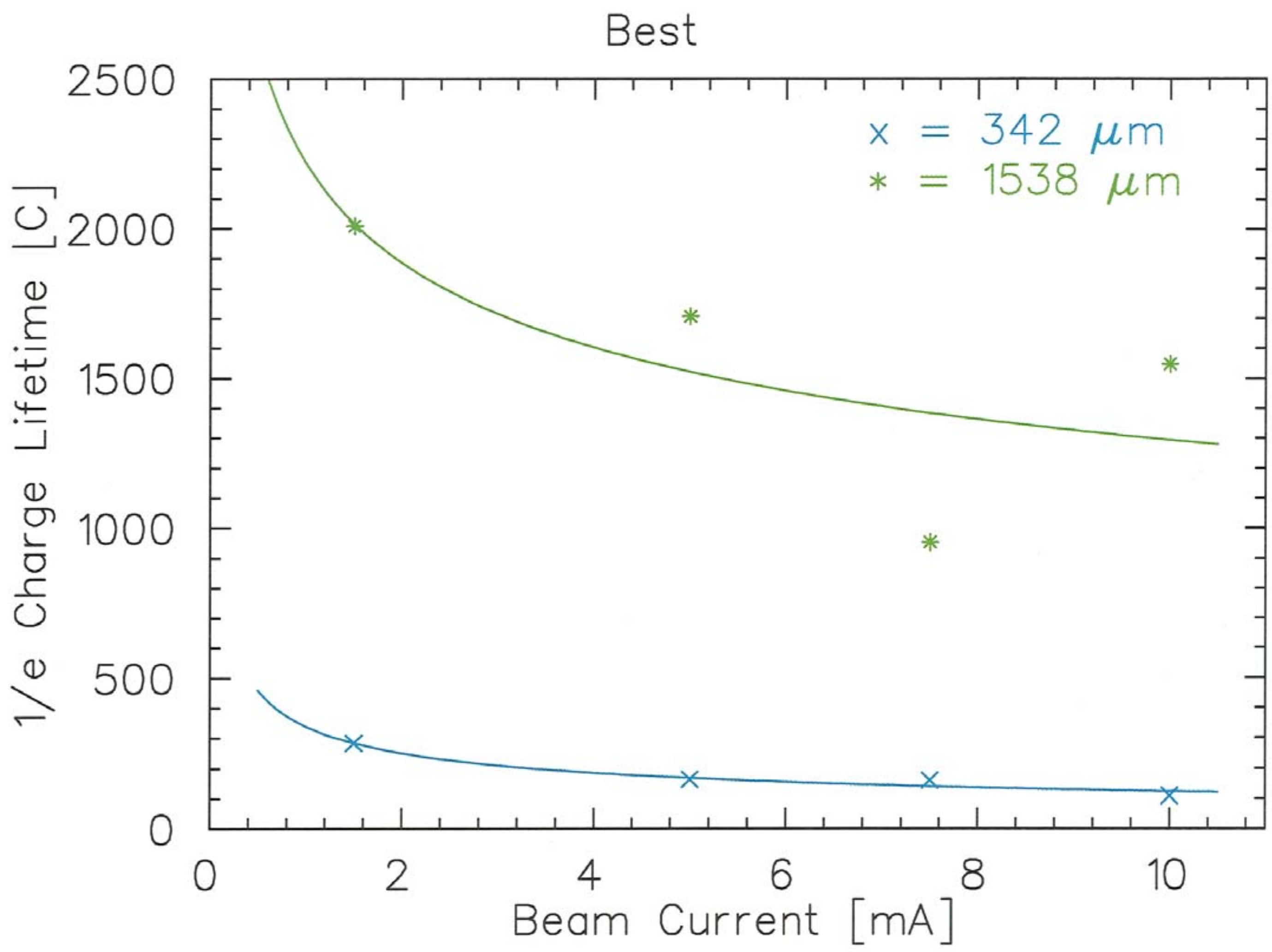
$$\left(\frac{842}{342}\right)^2 = 6.1$$

1/e Charge Lifetime: 1538um laser spot, from two locations

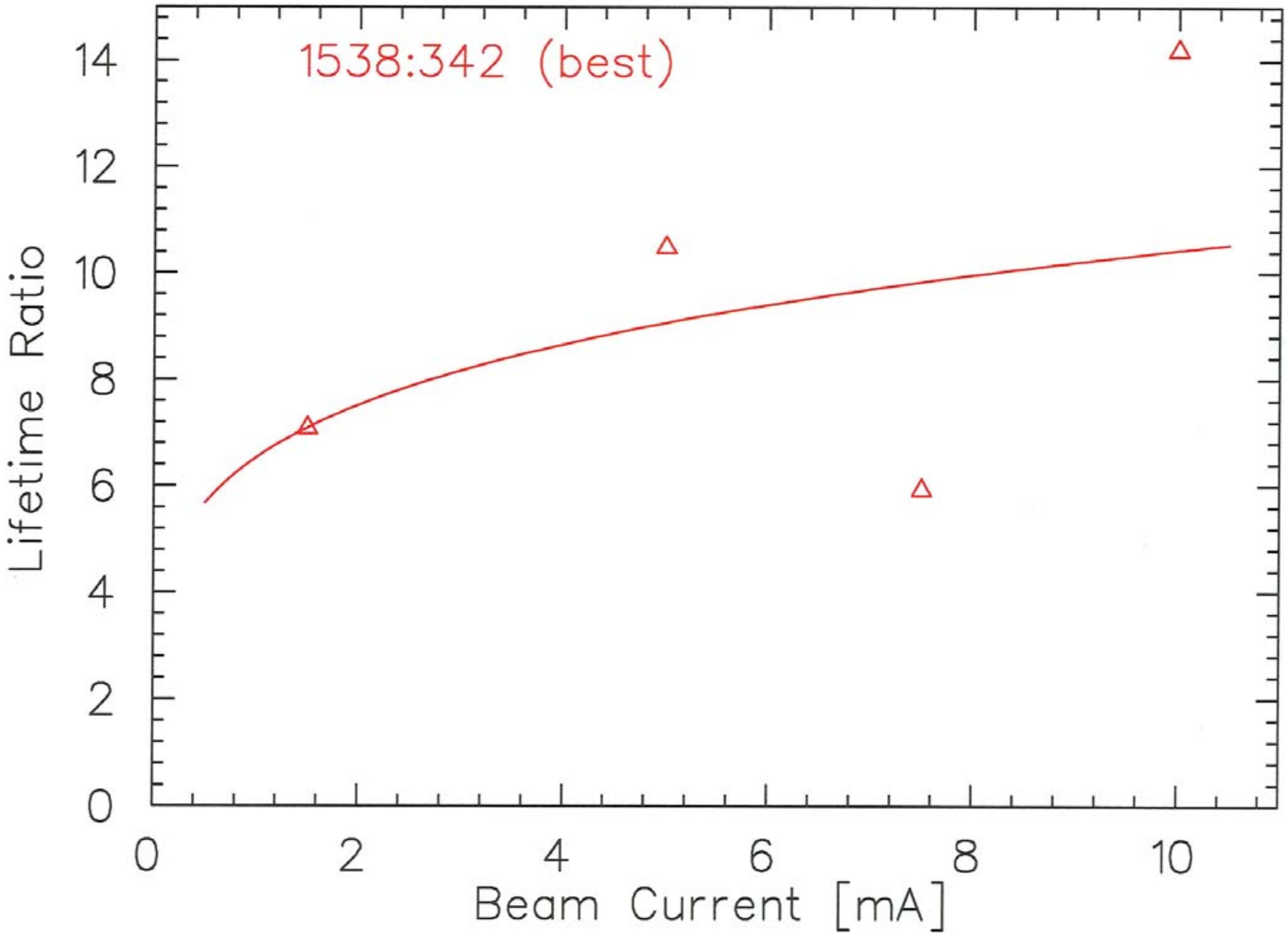


Location2 further from electrostatic center by ~ 400um

342 um and 1538 um laser spots from same "good" location



Lifetime enhancement? YES, but not what simple picture predicts



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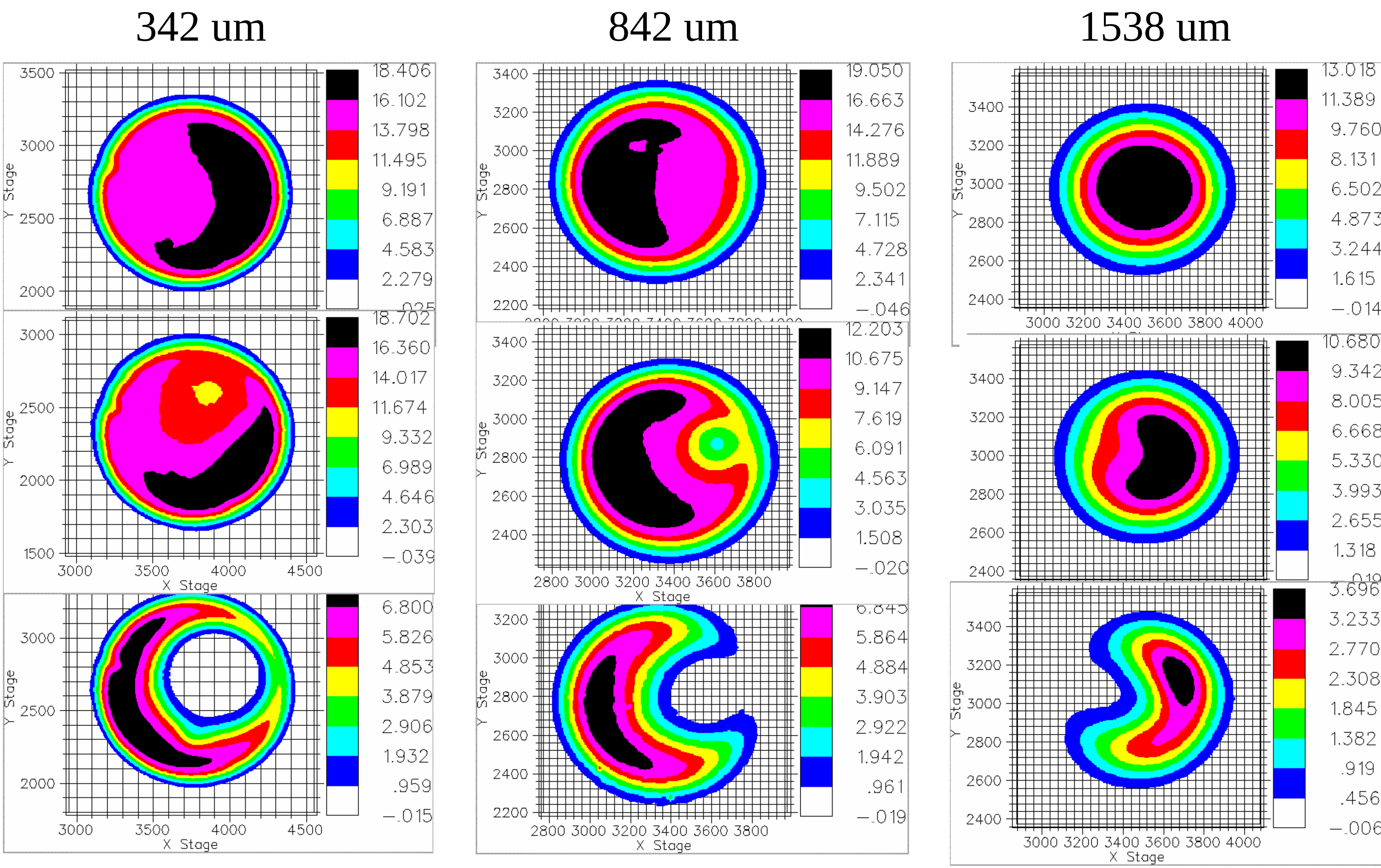
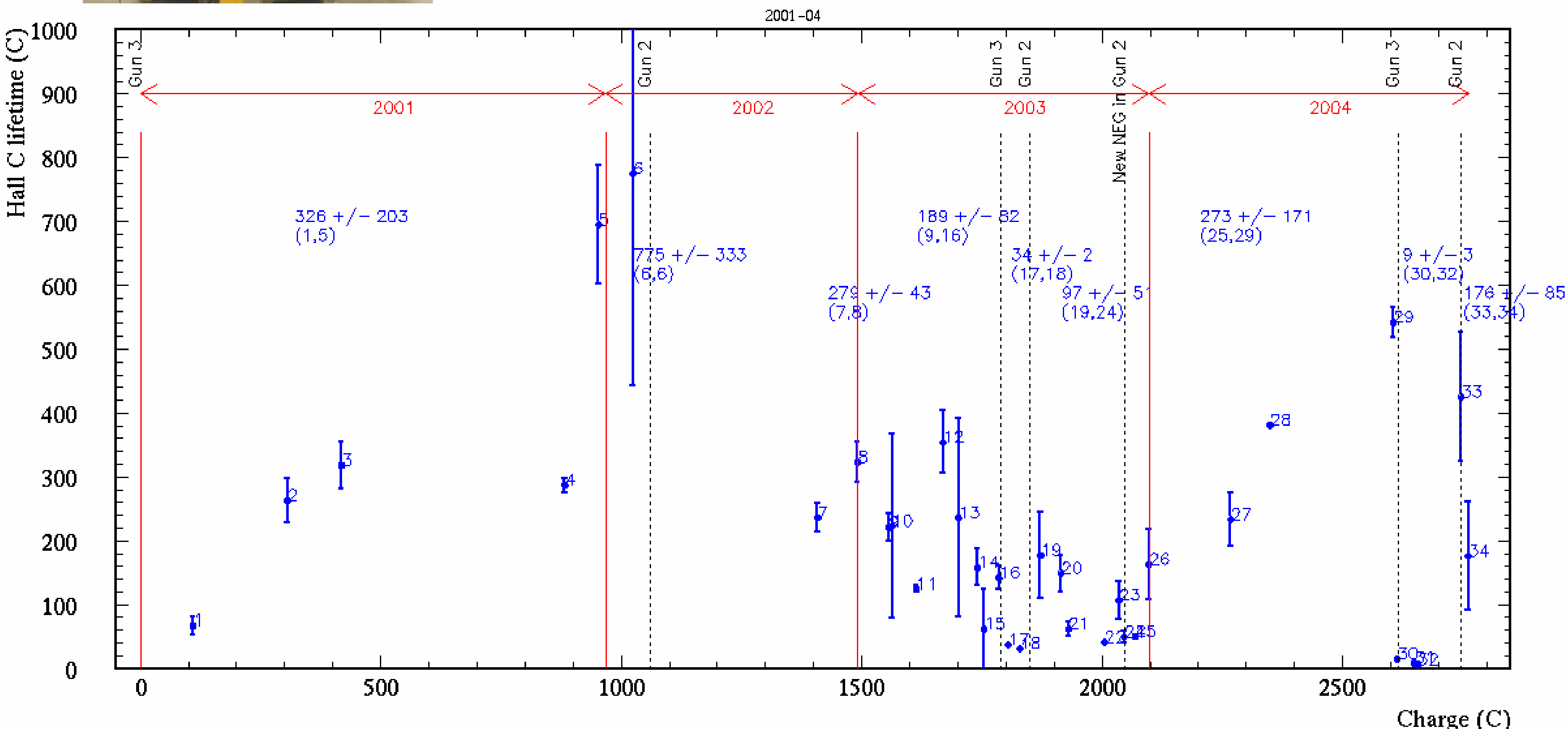


QE reduction at electrostatic center and overall

CEBAF 1/e charge lifetime similarly "random"



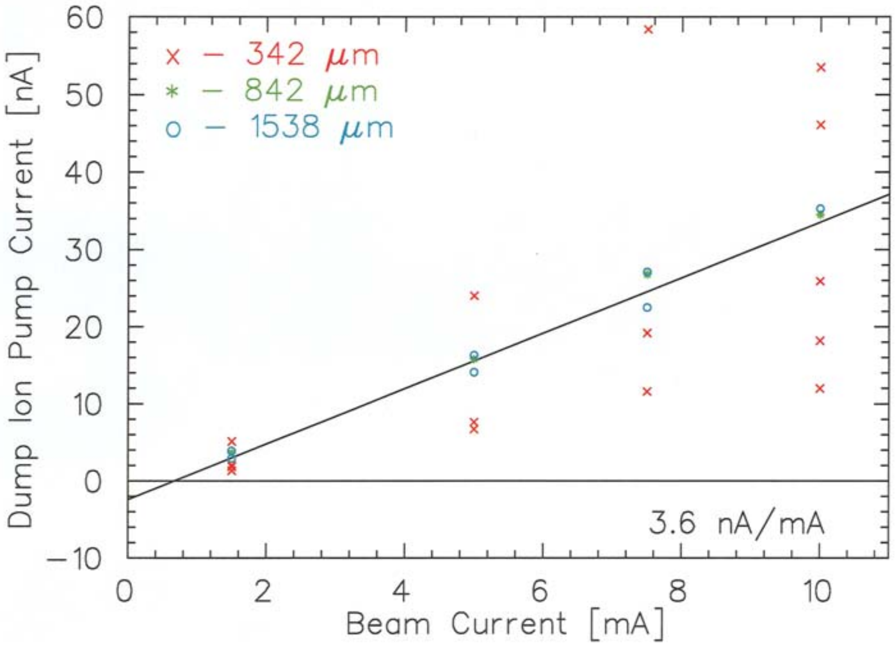
Charge extracted from CEBAF gun over 4 year period

“Obvious” Conclusions;

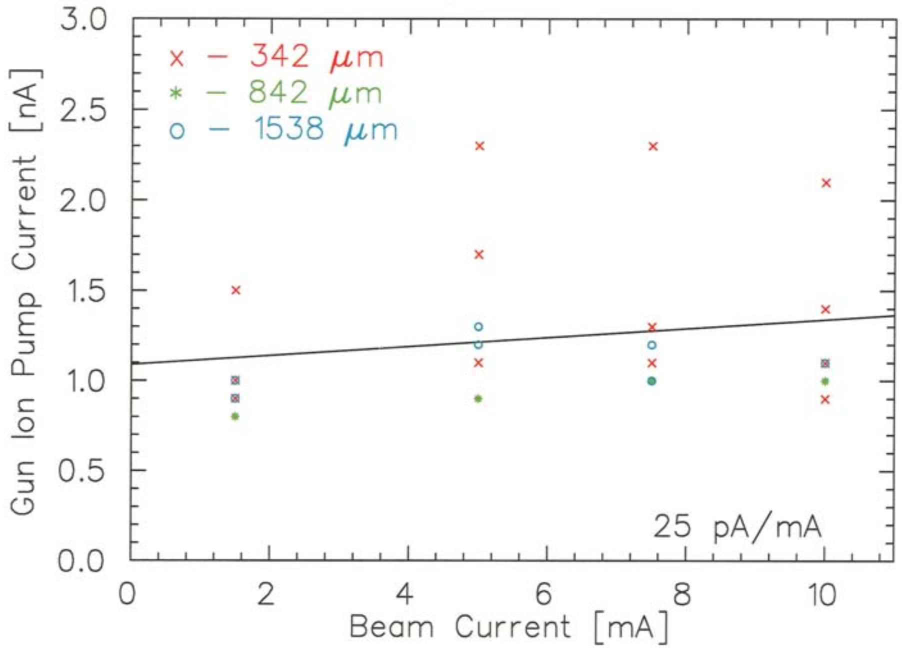
1) Some of the runs with 1538 um laser spot provided very good charge lifetime > 1000 C at beam currents to 10 mA! World record?
2) Good evidence for lifetime enhancement using larger laser spot. (Simple scaling argument likely not valid)
3) Charge density lifetime numbers with 342 um laser spot are comparable to CEBAF numbers with high polarizaiton material. > 2x10^5 C/cm2
4) Unfortunately (for those building high current guns), good charge density lifetime not maintained at large laser spot sizes (~ < 1x10^5 C/cm2)

“Not so obvious” Conclusions;

1) Simple exponential decay not always appropriate
2) Good charge lifetime not clearly correlated to good gun vacuum (at least gun ion pump current).
3) (so far) it has been difficult to identify conditions that lead to long charge lifetime. Spot location on photocathode seems to be very important. Radial position: further from EC is better. But not whole story.
4) When using simple a / i^{b} fit, b ranged from 0.2 to 1.3 for entire set of runs. b = 1 implies strict current dependence (OK), b > 1 implies current + vacuum dependence. b < 1 significant?
5) Where do ions go? “Beaming”? Does the potential of the beam begin to play a role? Modeling required.



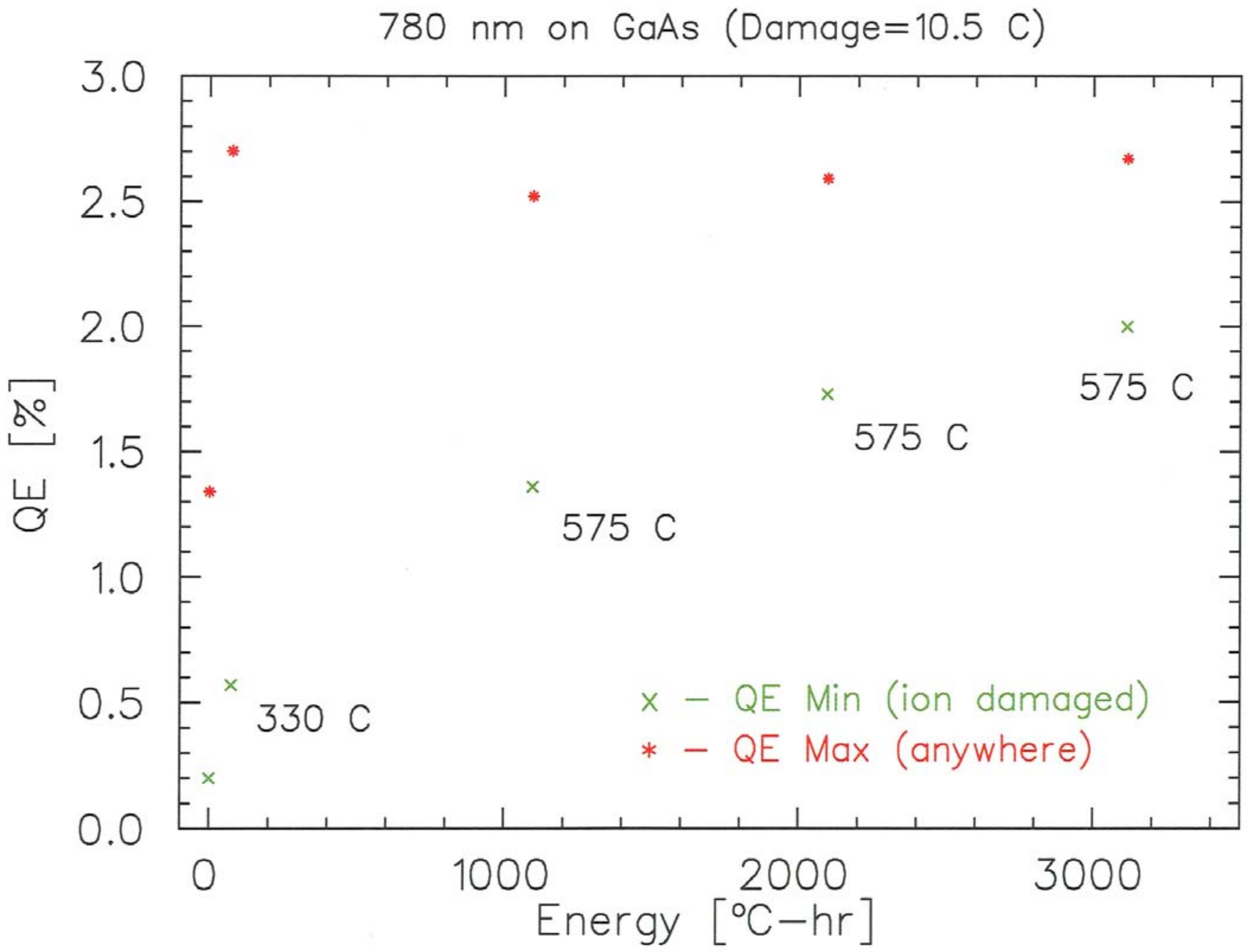
Dump Ion Pump Current scales with beam current

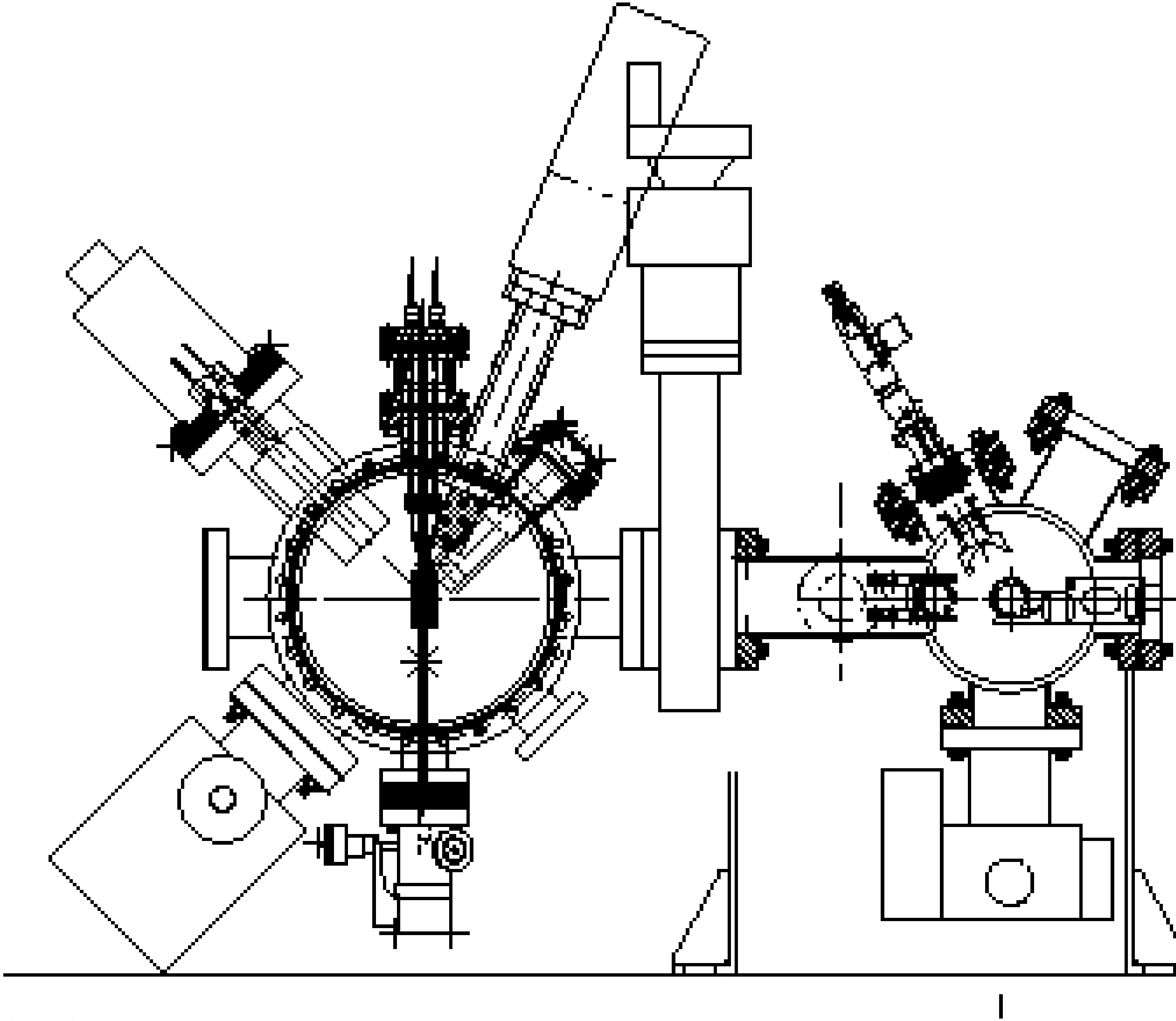


Not obvious that gun ion pump current scales with beam current

Best charge lifetime not necessarily associated with best gun vacuum (in this case, ion pump current)

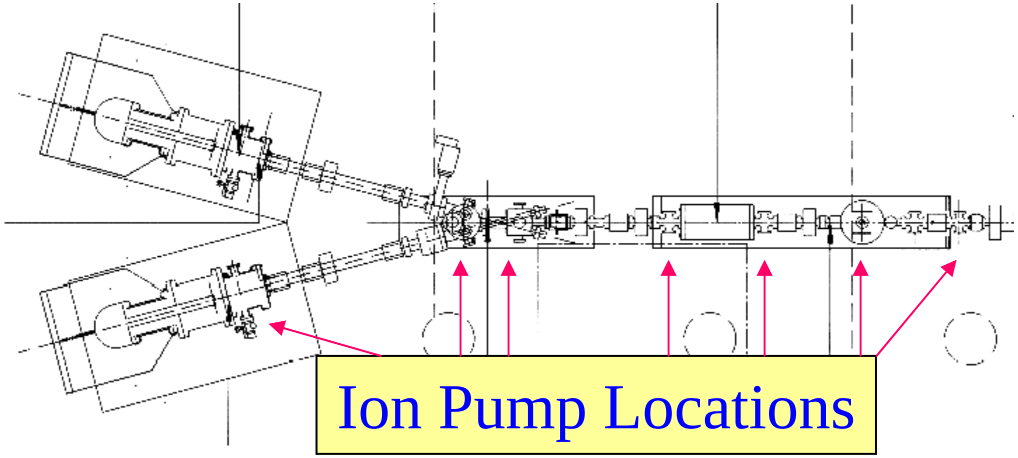
QE recovery following heat treatment and reactivation



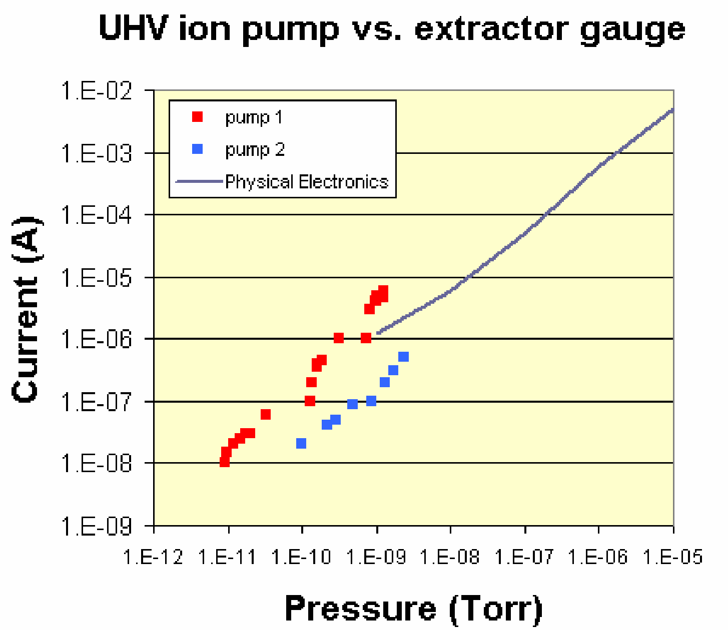


Ion Pump Power Supplies with nanoA Current Monitoring

Designed and constructed by J. Hansknecht



"Free" pressure monitoring at 10^-11 Torr



Pumps detect bad orbit and beamloss