Status of high intensity polarized electron gun project at MIT-Bates

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General Information

- Polarized electron guns utilize GaAs photo cathodes.
- When a polarized laser beam strikes the cathode, polarized electrons are ejected.
- Photocathodes must have an atomically clean surface and they must be activated by heating to about 600°C and applying Cs and NF_3 to the surface.
- UHV conditions are required in the gun. Any traces of gases (excluding hydrogen and noble gases) poison the crystal.

eRHIC (Linac-ring version)

Requires a polarized electron source with an extremely high average current (at least 10 mA).

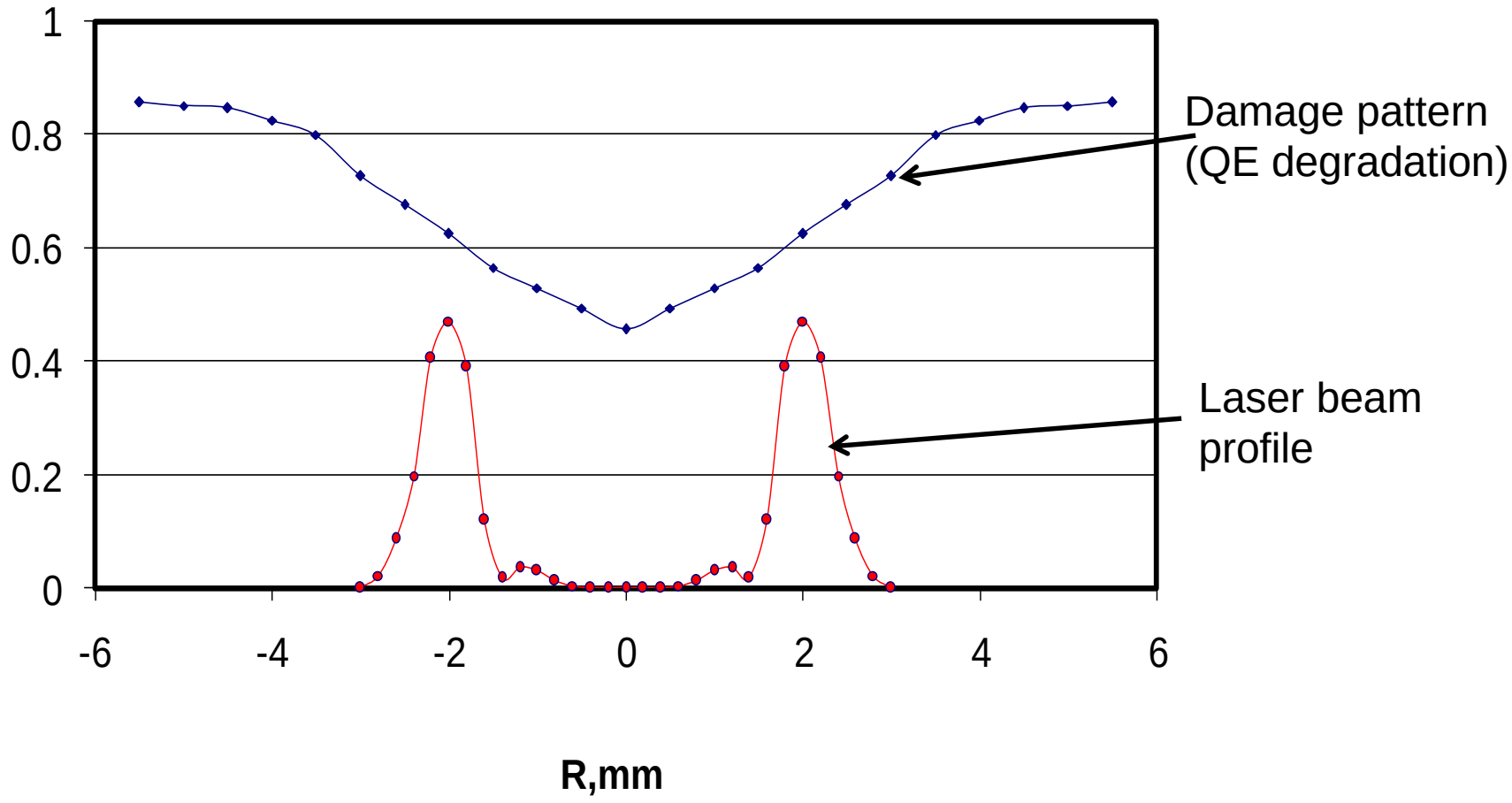
- Modern state-of-the-art guns produce ~100-200 μA
- Average current of ~ 1 mA achieved in tests at JLab and Mainz;
- Average current of up to 10 mA achieved at Mainz with very short lifetime (needs active cathode cooling)

Main problem – ion back bombardment.

Anode hole acts like a focusing lens for ions.

Ion damage is most severe at the center of the cathode.

Ion damage mostly the center of cathode (Bates results)



High Intensity Polarized Electron Gun

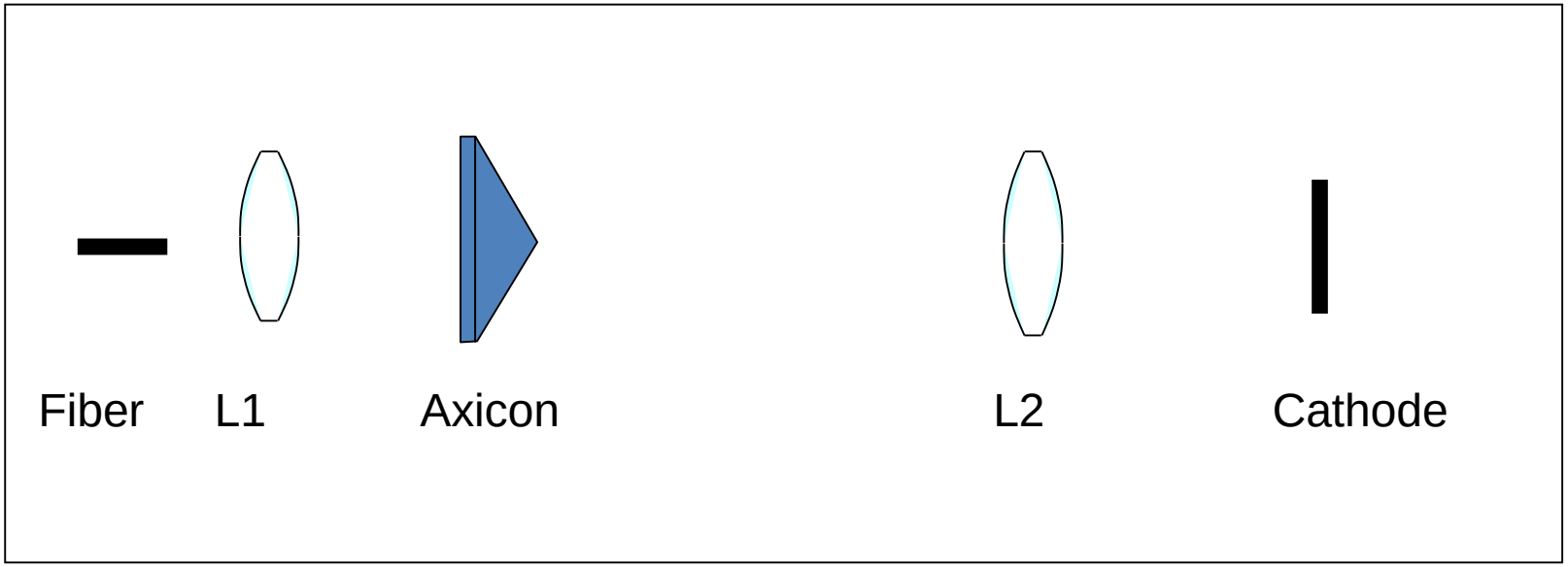
The principal points to achieve high average current:

- Large area cathode.
- Ring-shaped emission pattern – ions tend to damage the central area of the cathode.
- Active cathode cooling.
- Only very small beam losses can be allowed near the gun ($<10^{-6}$); many simulations performed with a proven code.

Additional requirements

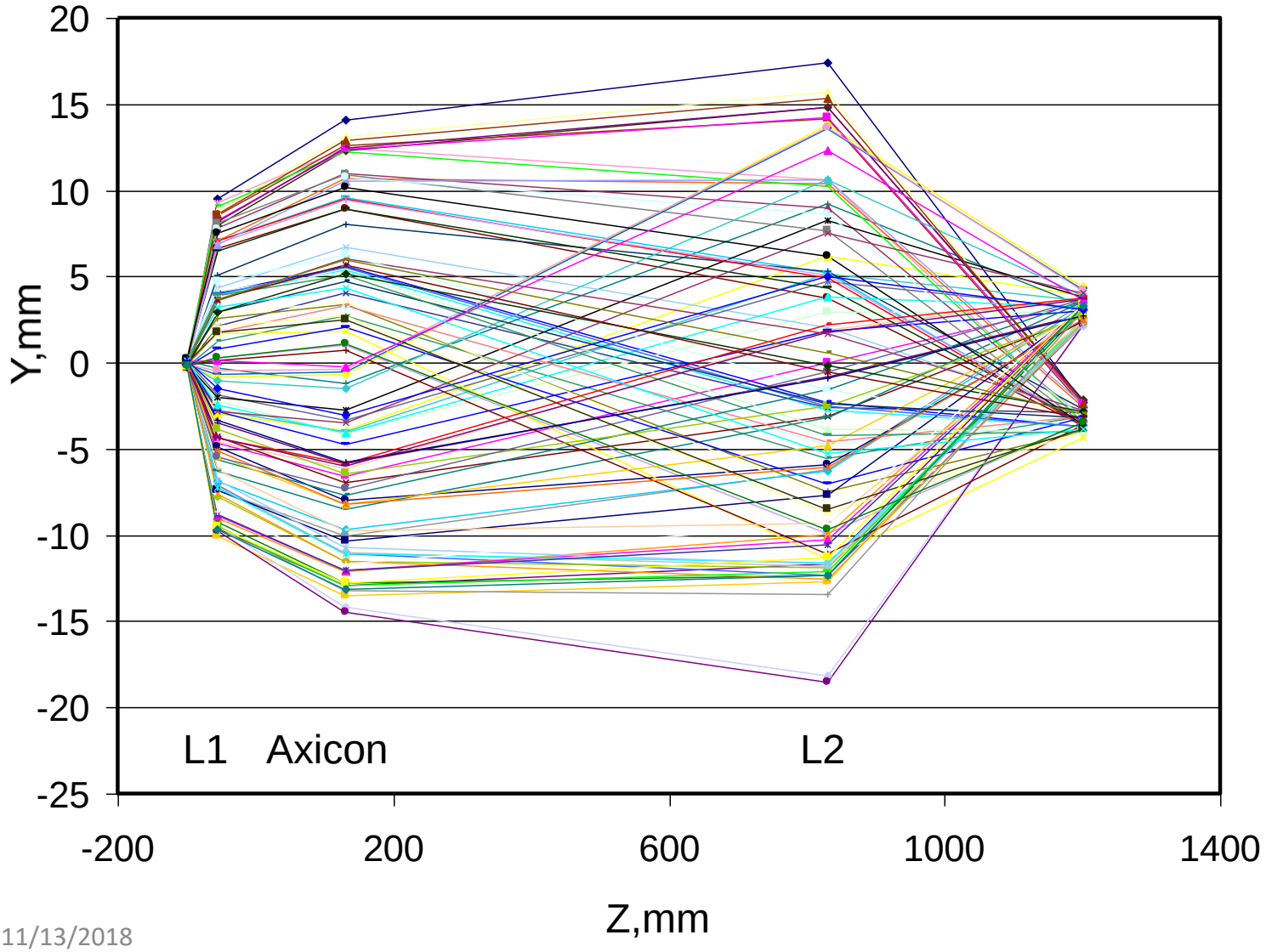
- Heat-cleaning and activation compromise UHV vacuum conditions; they should be done in a separate chamber (preparation chamber).
- It takes months to achieve good vacuum, so gun chamber and preparation chamber should never be vented. New cathodes should be loaded into the system via load lock chamber.

Ring-shaped Laser Beam



Axicon (conical lens) in combination with a converging lens (L2) produces ring-shaped beam in the focal plane of L2. Lens L1 reduces the laser beam divergence (25° from the fiber). Without axicon, a very small beam spot will be produced. QE can be mapped across the cathode by moving L2.

Axicon-based System Simulations



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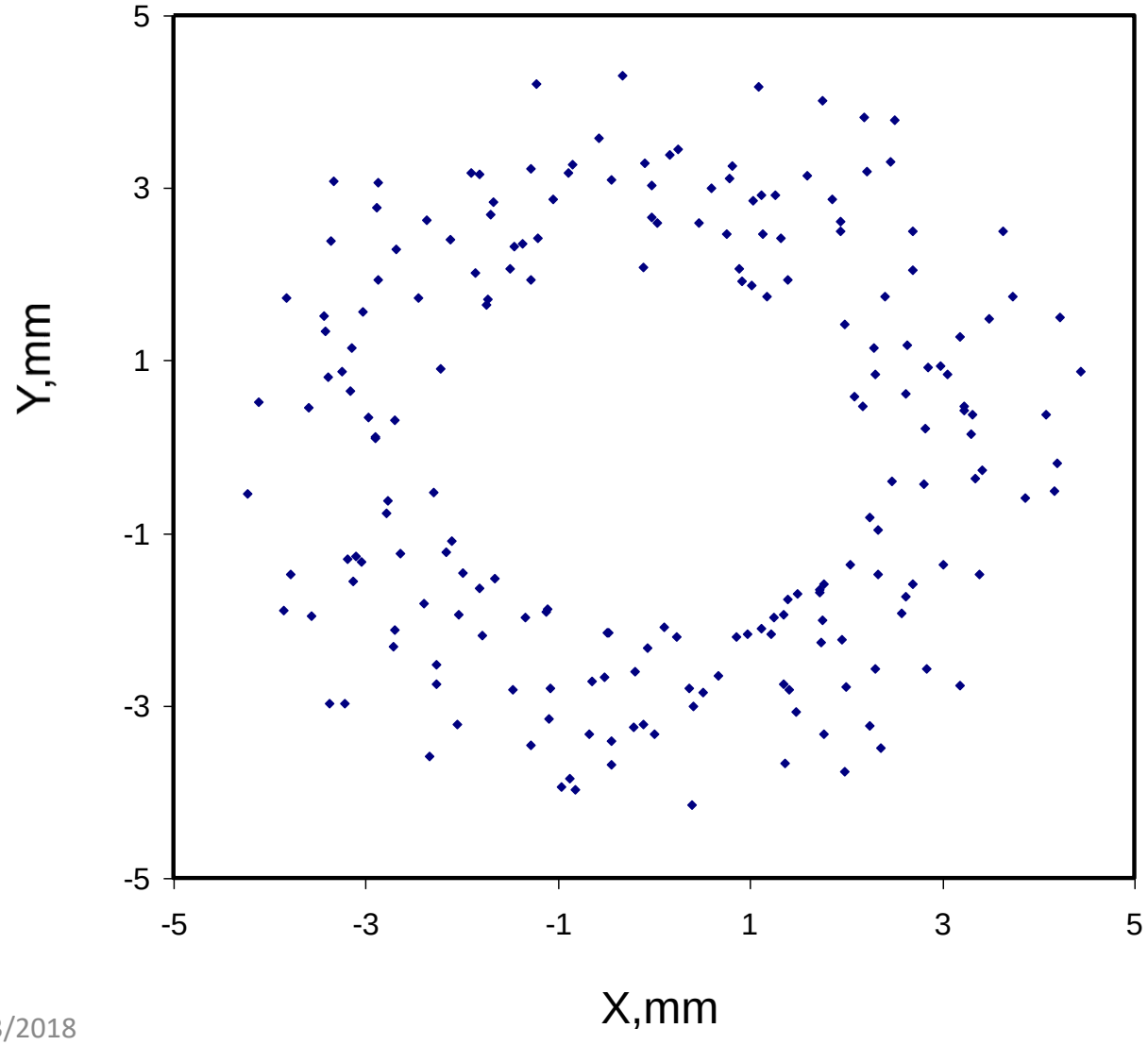
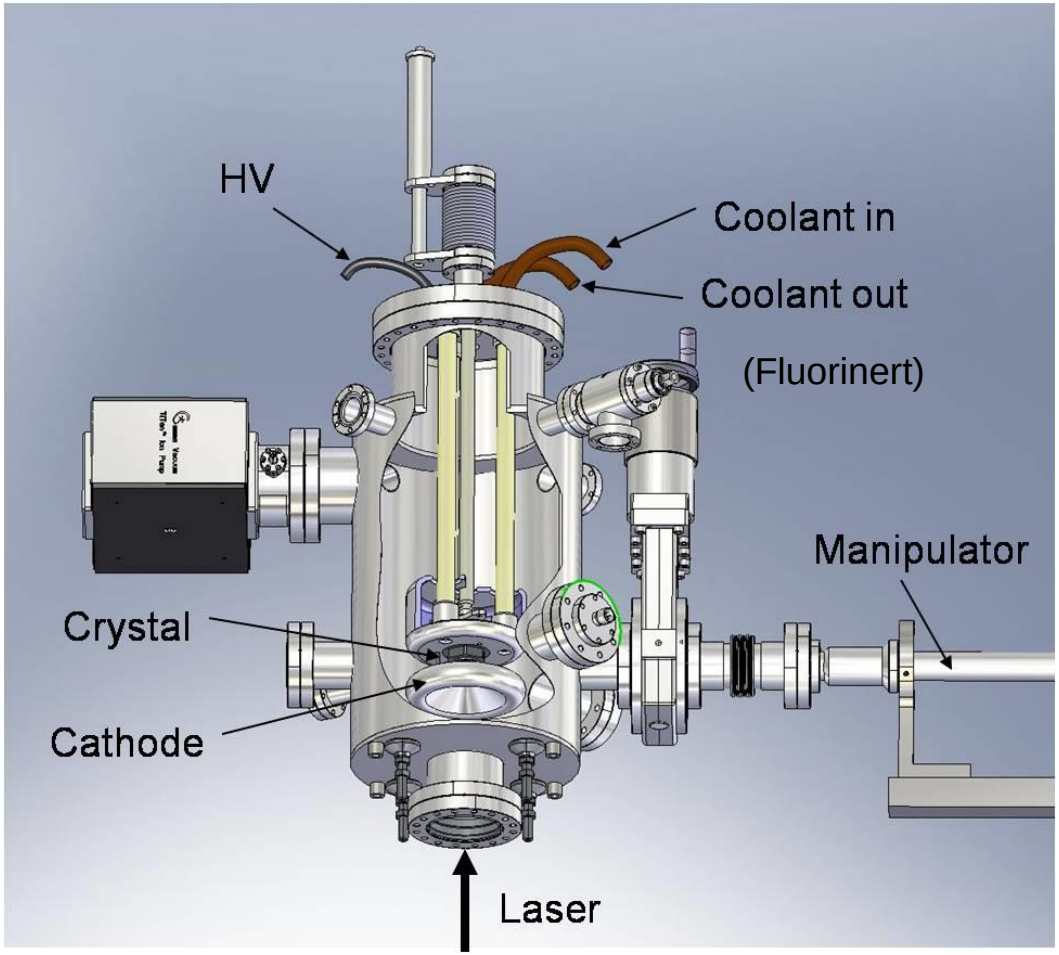
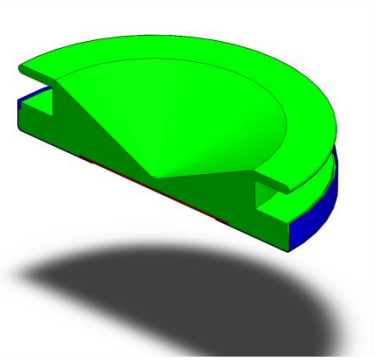


Cathode cooling



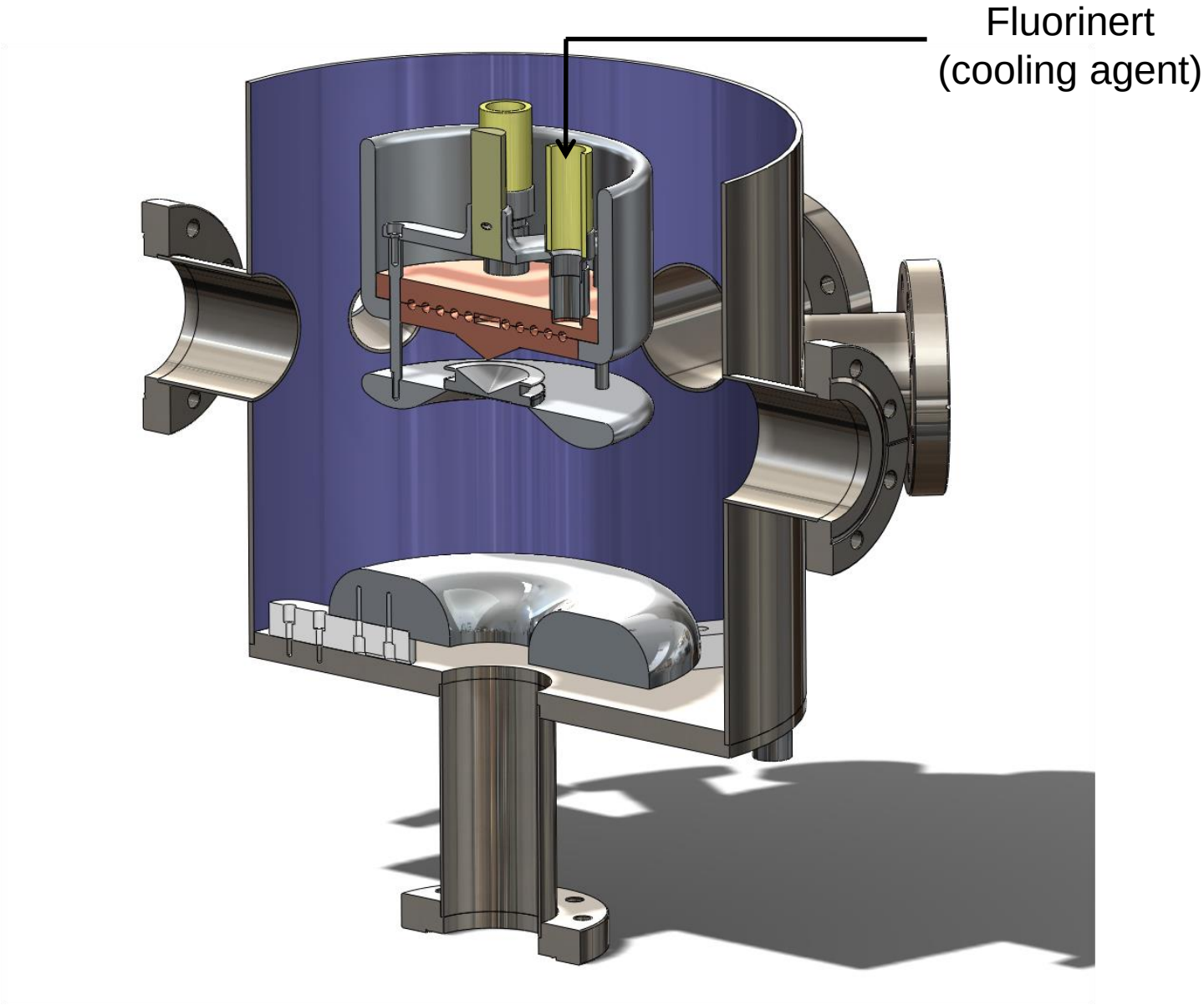


Cathode puck (Moly)

Heat exchanger

Up to 40 W of laser power

Cathode – anode assembly



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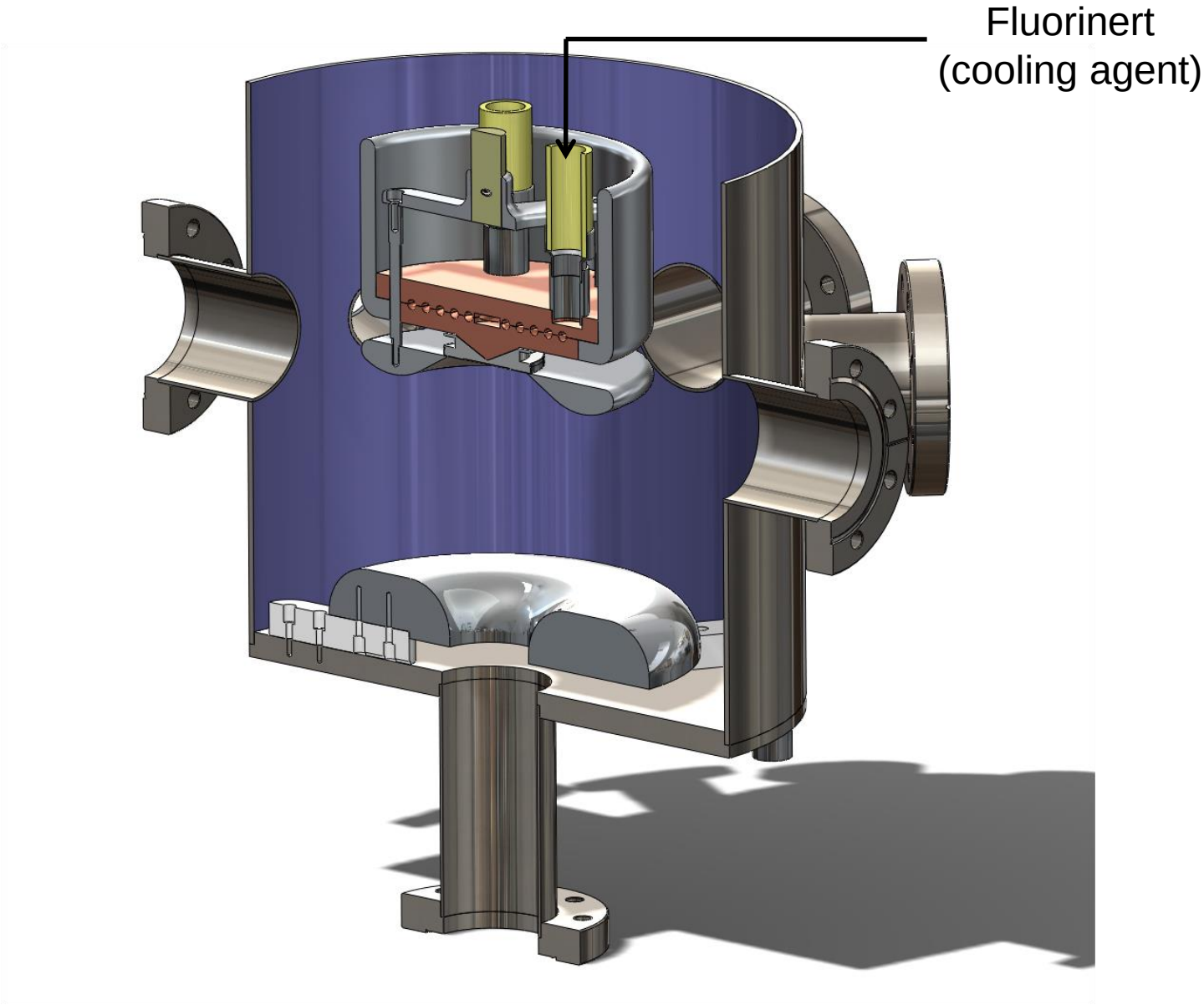
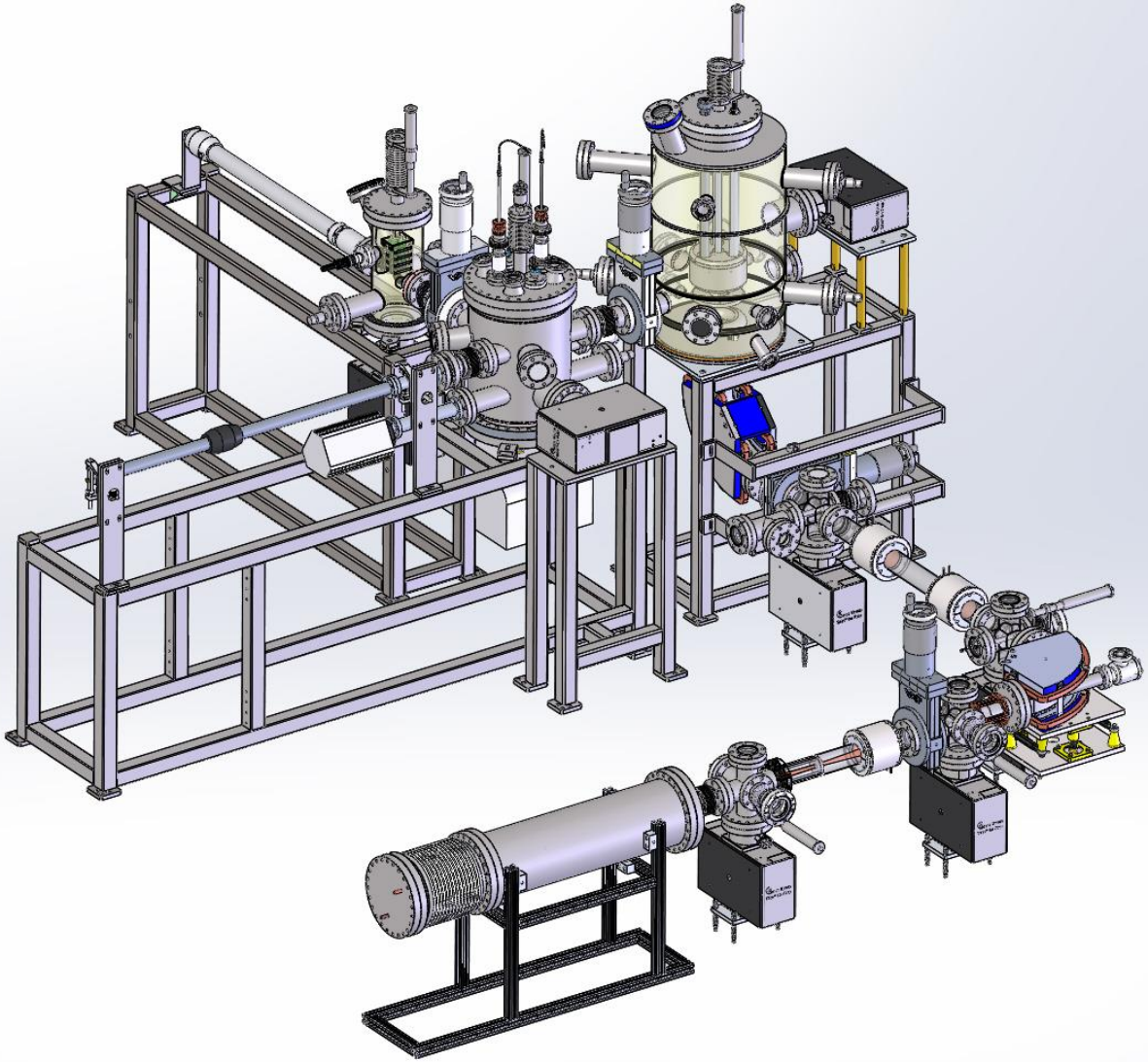
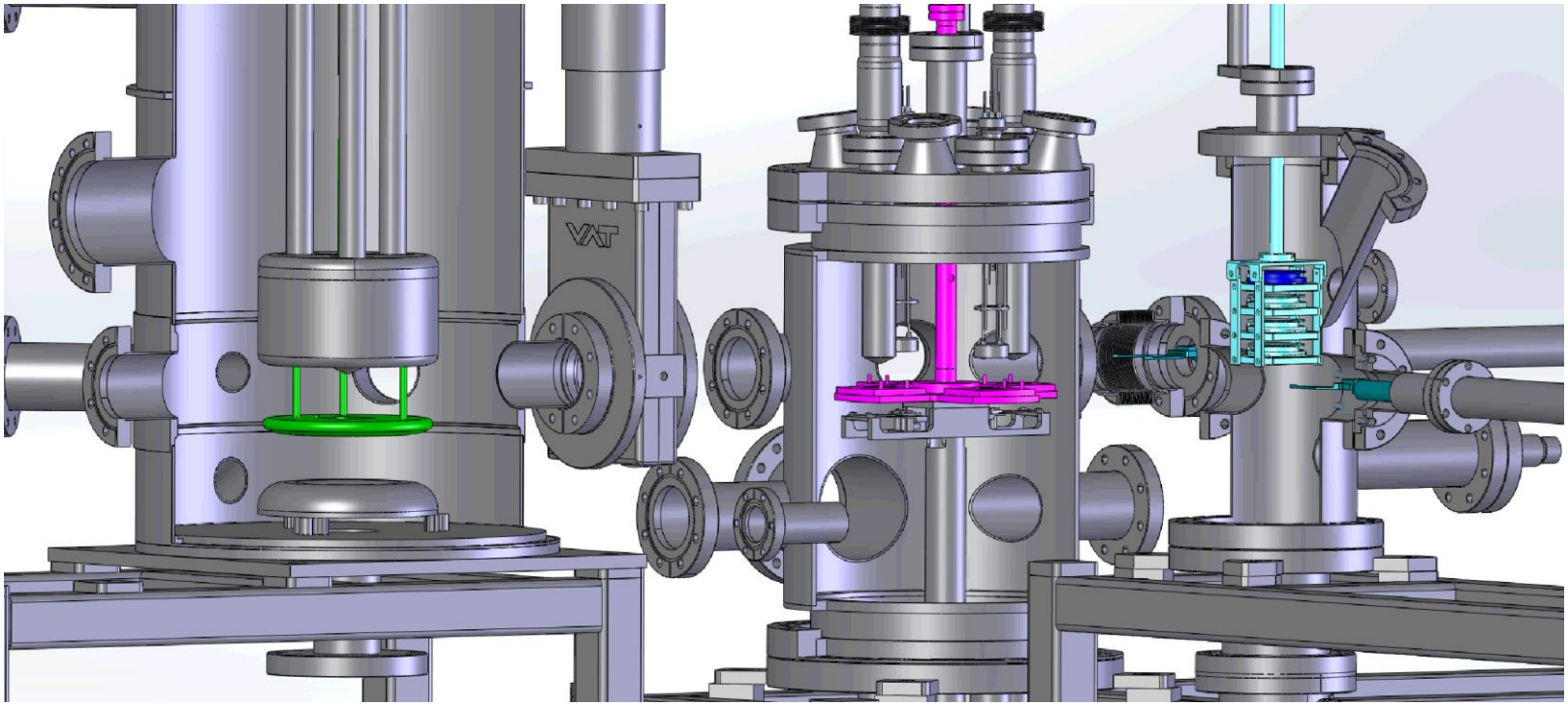
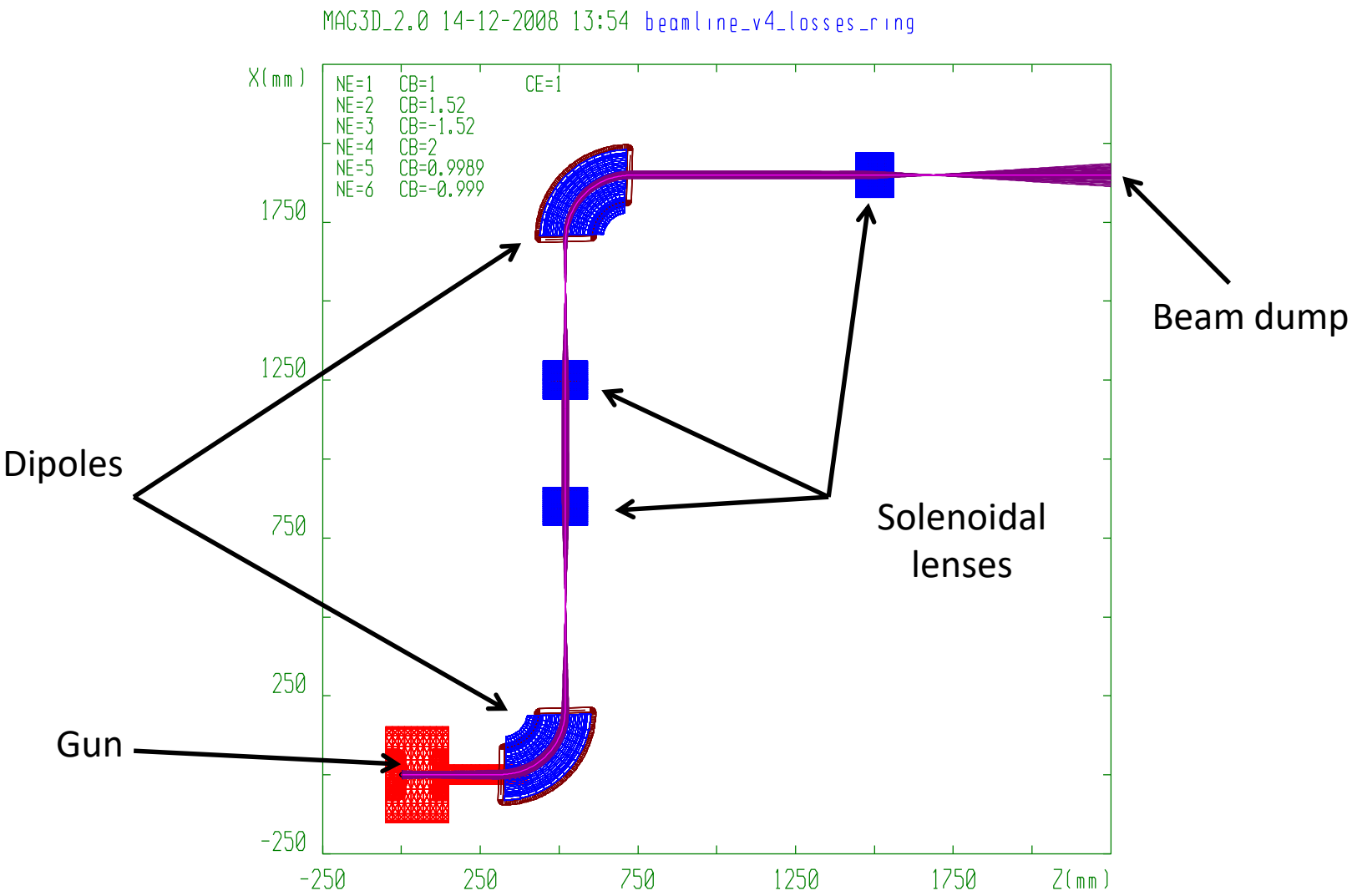


Gun + beam line




VAT

Beam line. Pipe aperture ~±34 mm.



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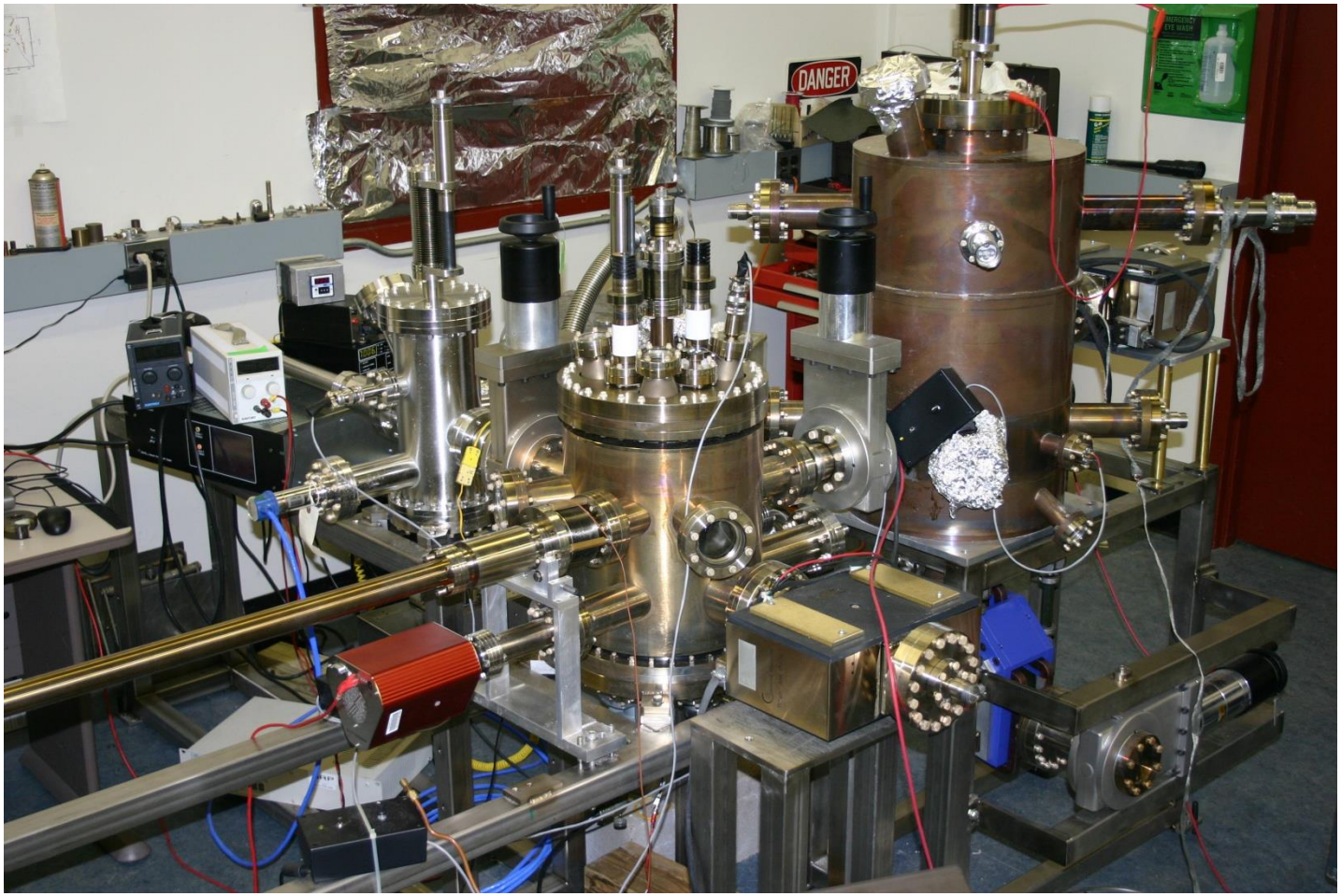


Vacuum features of the chambers

Gun chamber:

•100 l/s Ion pump with 400 l/s NEG and 4 additional 400 l/s NEGs.

• The chamber walls are thin (~ 3 mm) to reduce outgassing.

• The chamber and most of the parts have been prebaked to 400°C before the final assembly.

• Bake-out at 250°C after the final assembly.

• Vacuum better than $1 \cdot 10^{-11}$ (all Hydrogen) (limited by RGA outgassing)

Prep. chamber:

•100 l/s Ion pump with 400 l/s NEG and 2 additional 400 l/s NEGs.

• Vacuum better than $1 \cdot 10^{-11}$ (all Hydrogen)

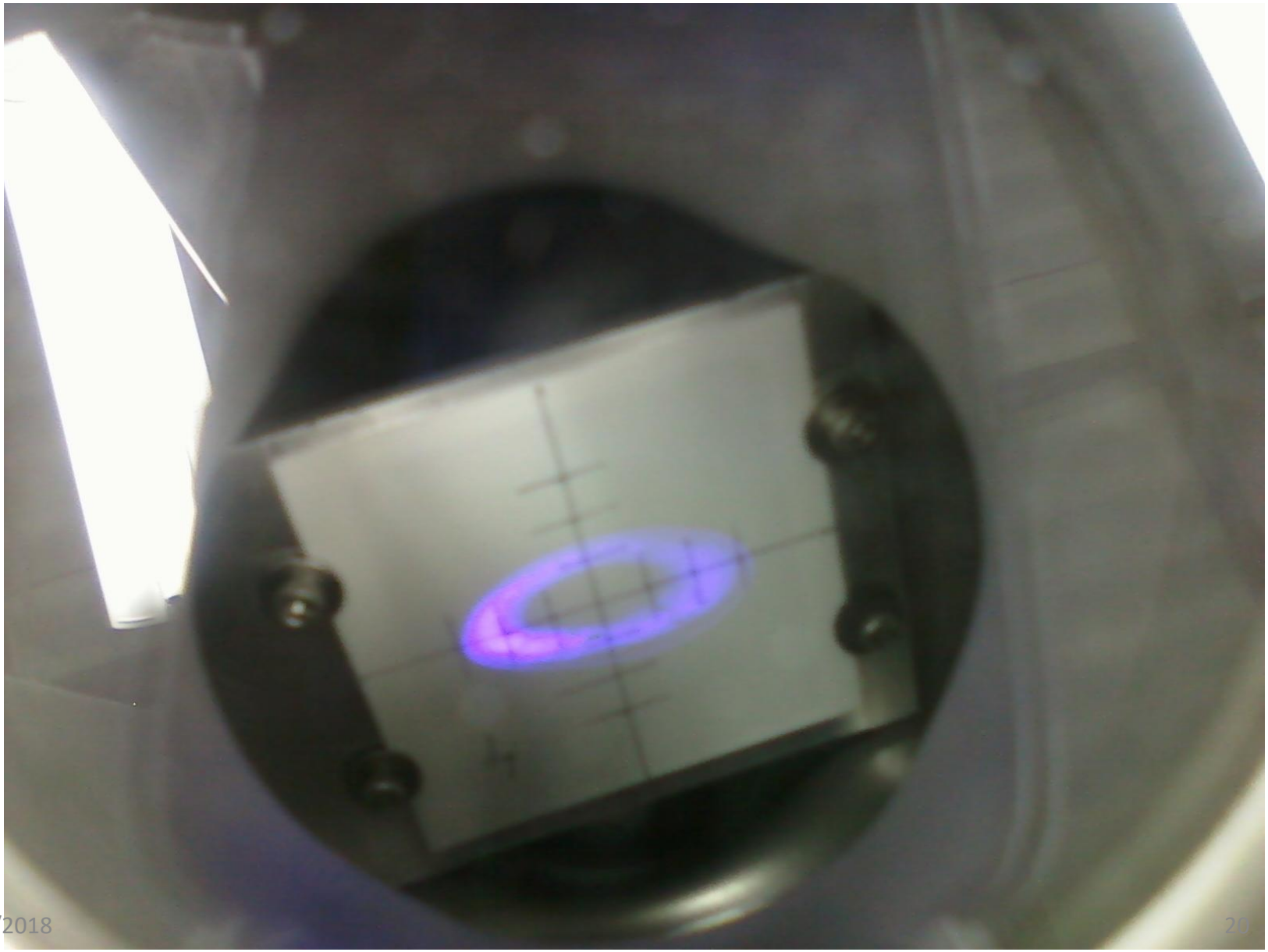
PROJECT PROGRESS

- FY 2007-2009 - preliminary simulations and tests. Beam simulations through the gun and entire beam line. Emphasis – no beam losses near the gun. Tests of active cooling. HV tests.
- FY 2010-2011 – gun chamber and preparation chamber built and assembled. Load lock and beam line designed, and manufacturing began.
- FY 2012-2013 – load lock built and assembled. Beam line and unbiased beam dump built.
- FY 2014-2015 – beam line and beam dump completed. First beam tests.
- FY 2016-2018 – beam tests.

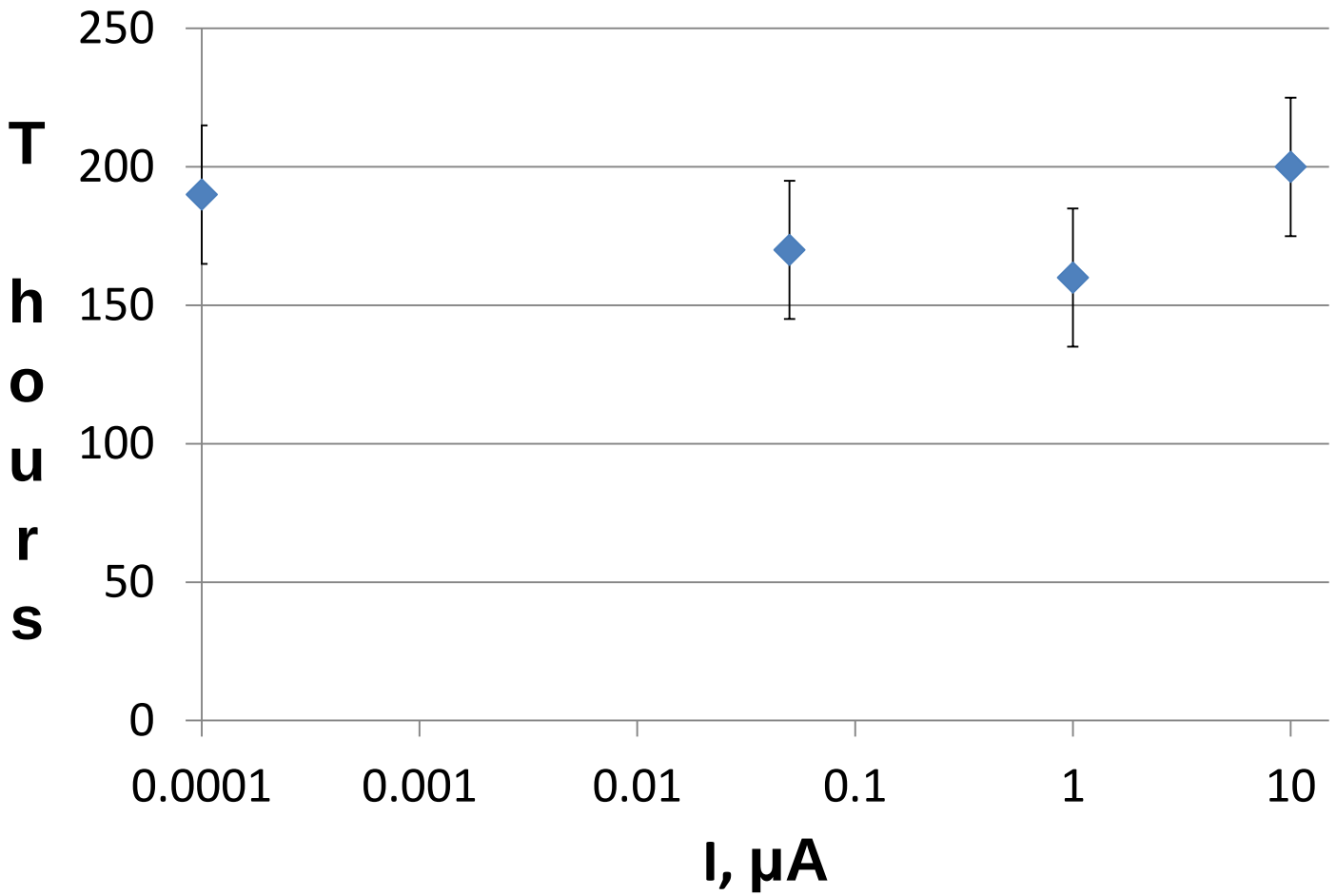
PROJECT PROGRESS

- Gun chamber, preparation chamber, load lock manufacturing and assembly – not a glitch. Excellent vacuum conditions. Reliable cathode transfer between chambers (good illumination and observation conditions). Very high QE (~2% at λ=805 nm) has been achieved.
- Beam line assembly – successful. Beam tuning through the beam line – the shape of the beam in full agreement with simulations.

Beam on BeO target

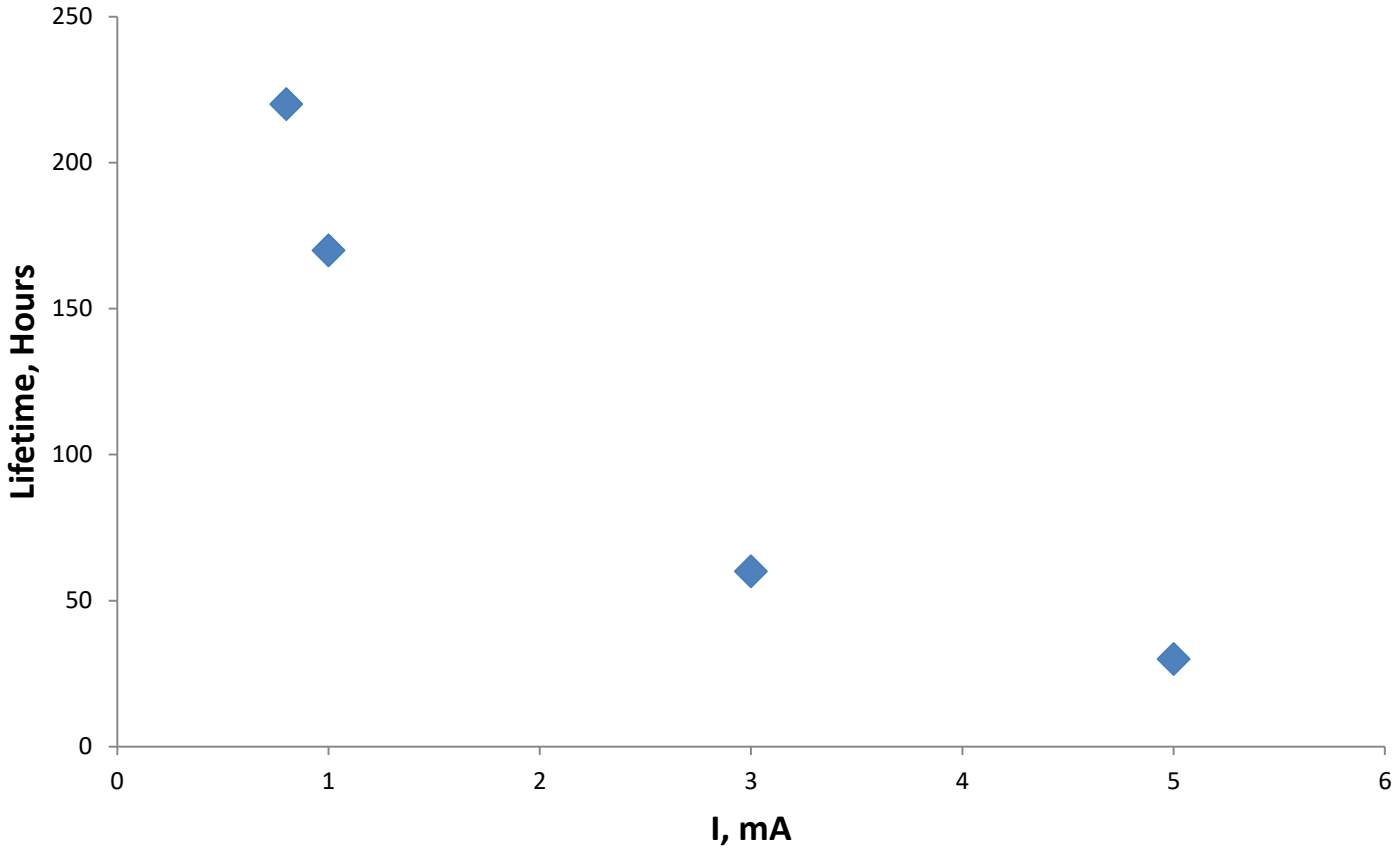


Lifetime measurements



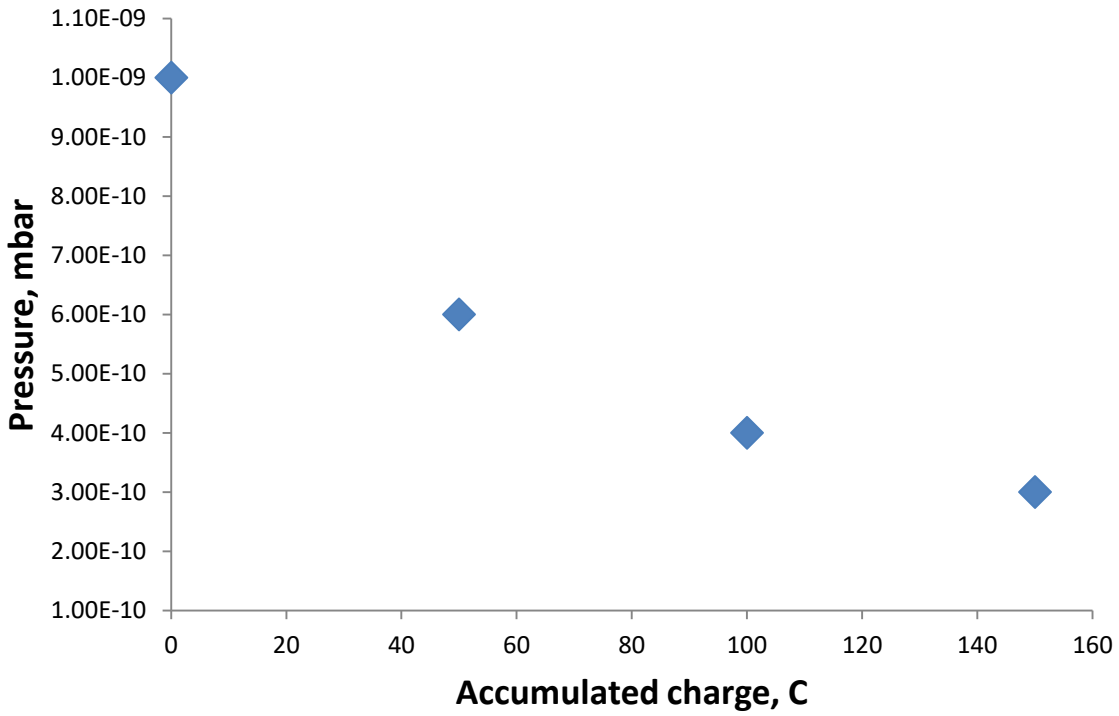
Lifetime doesn't depend on the current – no significant ion back bombardment at this level !

Lifetime measurements at mA range



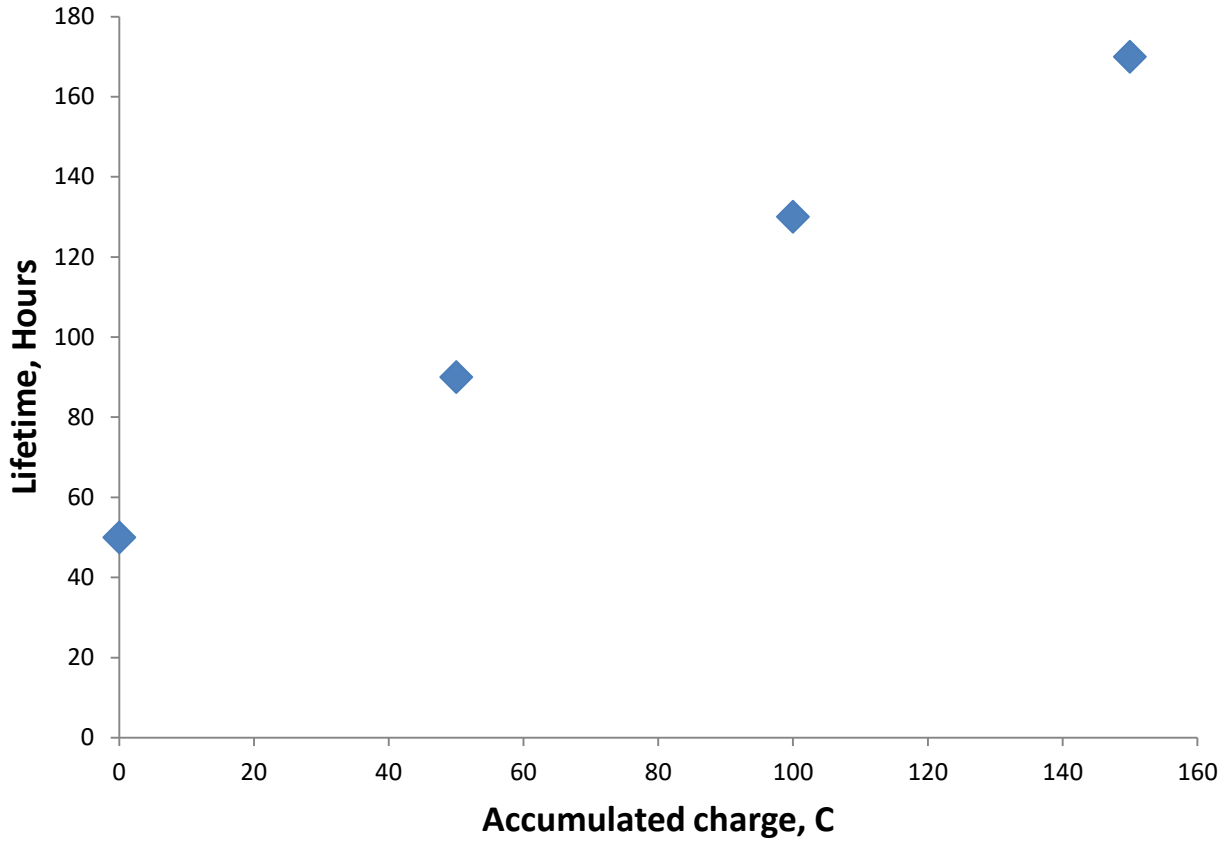
The lifetime is dominated by outgassing in the beam dump.

Pressure in the beam dump with 1 mA beam



Beam slowly outgasses the beam dump and the vacuum conditions steadily improve.

Lifetime with 1 mA beam



The lifetime improves accordingly.

Beam dump outgassing

Why do we believe that beam dump outgassing dominates the lifetime?

- When we run the RGA in the beam line it shows a significant increase in pressure at high current, especially for hydrogen. This is natural since the aperture conductance for hydrogen is 3.5 times higher than for air. But when we steer the beam anywhere in the beam line, the RGA readings do not change. This is a strong indication that we have little if any beam scraping in the beam line.
- We mapped the cathode QE after the long run and found that QE degradation is uniform across the crystal. This fact indicates that the degradation was caused by cathode poisoning, not by ion back bombardment.
- During the long tests we lost 99% of QE of the cathode. But when we moved the cathode into the preparation chamber, several minutes of cesiation restored the QE to about 70% of its original value. This is another strong indication that ion back bombardment plays a small role in cathode degradation. Ion back bombardment damage usually can be fixed only by heat-cleaning.

CURRENT STATUS

- We believe that we made a lot of progress with the gun.
- Good vacuum conditions have been routinely achieved in the gun and preparation chambers.
- Very reliable cathode transfer between chambers in vacuum.
- High QE in every activation (~2% at λ=805 nm).
- Active cooling allows delivering up to 40 W of laser power on the cathode.
- The beam tune through the beam line and the size and shape of the beam are in full agreement with simulations.
- The lifetime of the crystal was measured at very high current. We measure $\tau \approx 170$ hours at I=1 mA and $\tau \approx 30$ hours at I=5 mA.
- With a fresh crystal, the gun produces 5 mA current with laser power of about 0.15 W. The gun is designed to take up 40 W of laser power. This means that even in the current configuration we can run 5 mA for about 300 hours before the cathode needs to be reactivated.
- We believe that even in the current configuration the gun meets the requirements for the linac-ring version of eRHIC.

BUDGET

FY	From BNL	From DOE	From DOE thru BNL	Actual cost
07-09	$444 K			$444 K
10-11	$150 K	$586 K		$515 K
12-13		$388 K		$505 K
14-15		$500 K		$291 K
16		$130 K		$135 K
17			$137 K	$233 K
18				$200 K
Total	$594 K	$1604K	$137 K	$2,323 K

Total funding: $2,335k

The funds were used for equipment, manufacturing and salaries

PROPOSED FUTURE WORK

We have several scenarios, a subject to availability of funds.

1. To complete CW tests.
2. To conduct tests with pulsed beam (high peak current).
3. To conduct tests with much larger average current
4. To build a real gun for Linac-ring eRHIC version

PROPOSED FUTURE WORK - 1

As a minimum, we want to finish the CW tests. The goal is to run 5 mA for a week non-stop.

Costs:

- Materials - 18K
- 2 months of physicist - 55K
- 0.5 months of engineer - 16K
- 1 month of technician - 18K
- **TOTAL - 107K**

PROPOSED FUTURE WORK - 2

We would like to conduct high peak current tests with a pulsed beam. In these tests we will measure the lifetime as a function of the peak current while keeping the average current constant. The goal is to achieve at least 500 mA peak current without affecting the lifetime significantly.

In order to conduct these tests we need to build a very large capacitor (120 kV, 10μF) to avoid the voltage sagging during the pulse.

Costs:

- Equipment - 30K
- 1 months of physicist - 28K
- 0.25 months of engineer - 8K
- 0.5 month of technician - 9K
- **TOTAL - 75K**

PROPOSED FUTURE WORK - 3

Can we run 50 mA instead of 5 mA ? It is possible, but in order to test it we need to reduce the contribution from the beam dump outgassing very significantly. One way is to increase the length of the beam line and add two more 90^{o} turns. Unfortunately, it would mean moving the system into a different location; the current room is not big enough. A better solution would be to build a biased beam dump. That would reduce outgassing by at least 2 orders of magnitude. But it is a rather cumbersome and expensive device.

Costs:

- Equipment - 120K
- 3 months of physicist - 84K
- 1 months of engineer - 31K
- 2 month of technician - 35K
- **TOTAL - 270K**

PROPOSED FUTURE WORK - 4

If the decision is reached to go ahead with a linac-ring version of eRHIC, or if JLab needs a high intensity polarized electron source to make polarized positrons, we can build a much better system than the existing prototype. We gained invaluable experience to be used in designing, building and operating a robust production system in the future. We have a very good understanding of which parts of the system should be modified to improve reliability.

Costs:

- Equipment - 250K
- 12 months of physicist - 335K
- 3 months of engineer - 95K
- 6 month of technician - 107K
- **TOTAL - 787K**