High Intensity Polarized Electron Sources

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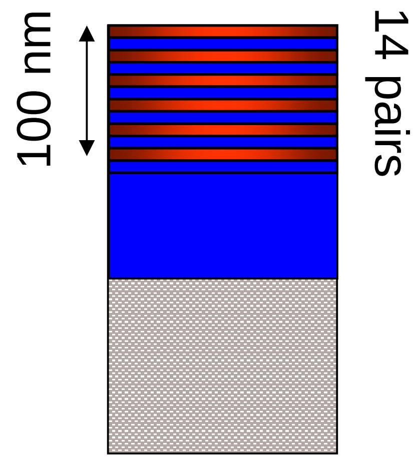
Polarized Electron Beam Requirements:

Good gun

Bake/Vent Gun
and New Load Locked gun

Good Photocathode

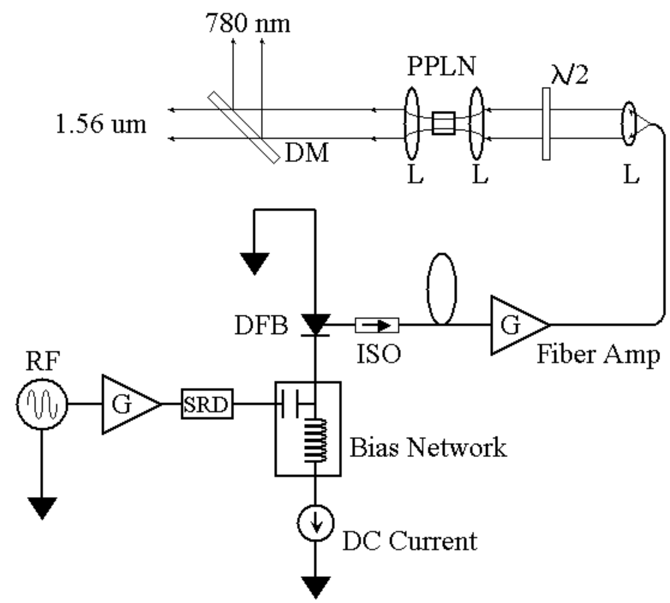
Superlattice GaAs:
Layers of GaAs on
GaAsP



No strain relaxation
QE ~ 0.8%
Pol ~ 85%
@ 780 nm

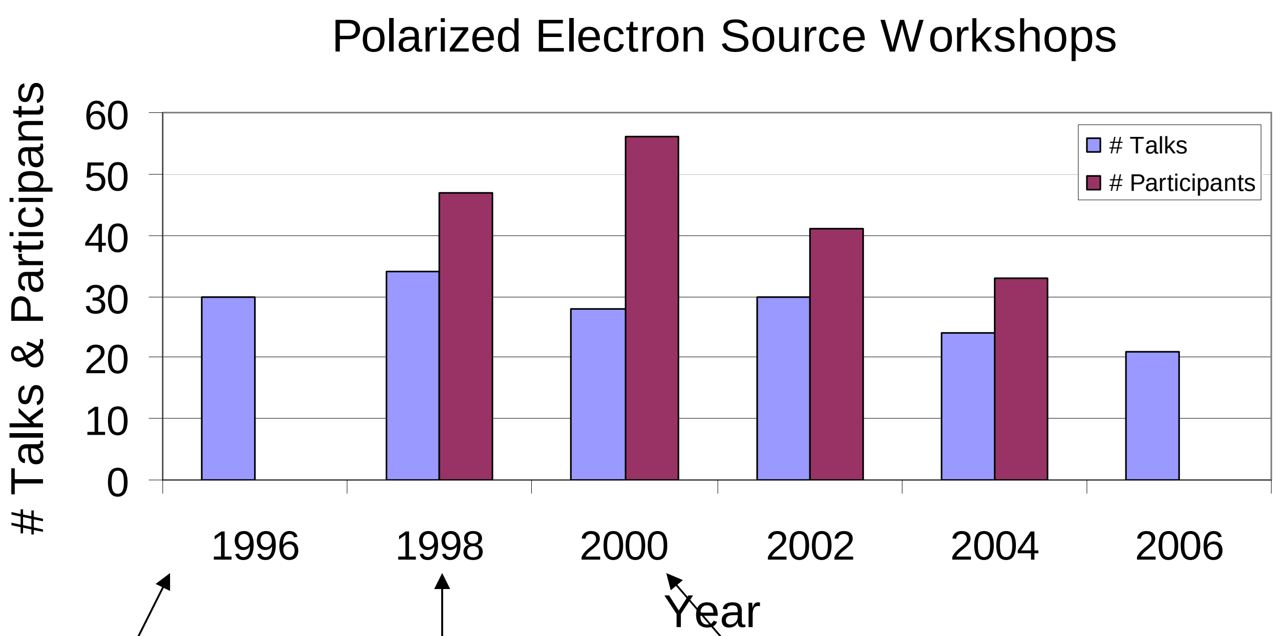
Good Laser

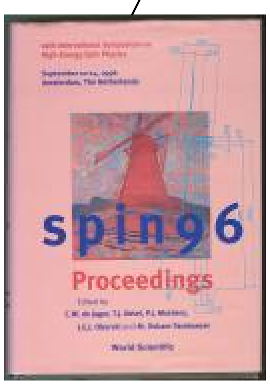
Fiber-based Laser

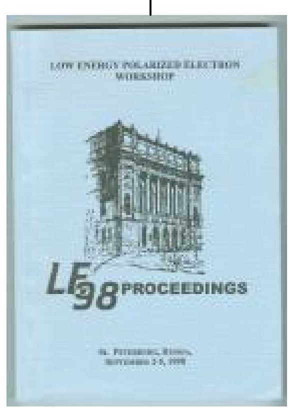


These items exist at many locations, with happy Users worldwide…..

Polarized Source Programs Worldwide







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Facility
Bonn-ELSA
CEBAF-JLab
Mainz Microtron
MIT Bates
Nagoya/JLC
SLAC SLC
NIKHEV

Reduced Scope (MIT Bates, Nagoya/JLC, SLAC SLC)

Closed (NIKHEV)

What Constitutes "High Intensity"?

Polarized Electron Beam - beyond the state of the art

- New experiments at CEBAF: Qweak and PRex (300uA)
- ILC (demanding time structure, 50x SLAC ave beam current)
- CLIC
- Electron Ion Collider
  - ELIC (1mA within macropulse at 85% pol)
  - eRHIC (25 to 250mA ave current at 85% pol)

Unpolarized Electron Beam

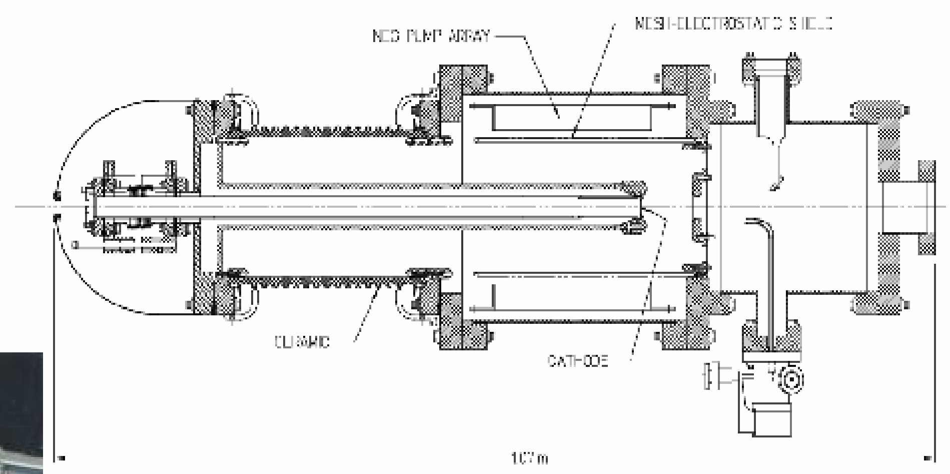
- JLab IR FEL (10mA and 350kV)
- Daresbury ERLP (modest current, 350kV)
- Cornell ERL (100mA and 750kV)
- JAEA ERL (50mA and 250kV)
- JLab 100kW FEL (100mA and 500kV)

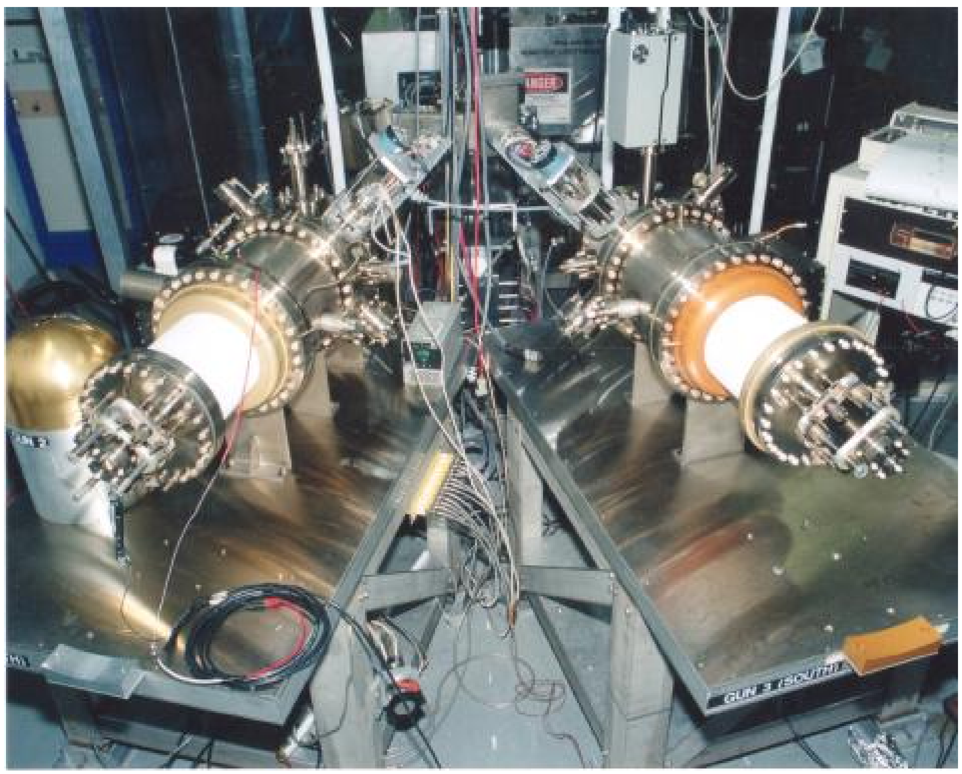
Preparing for New Experiments at CEBAF

- Commercial strained-superlattice photocathode
  - Consistent 85% polarization, ~ 1% QE
- Fiber-based drive laser
  - Low maintenance, No feedback loops, Higher power than Ti-Sapphire lasers
- CEBAF load-locked gun
  - Improved vacuum
- High Current R&D
  - Lifetime scaling with laser spot size
  - 1mA sustained operation at high polarization!

CEBAF 100kV polarized electron source

- Two-Gun Photoinjector - One gun providing beam, one “hot” spare
- vent/bake guns – 4 days to replace photocathode (can’t run beam from one gun while other is baking)





- Activate photocathode inside gun – no HV breakdown after 7 full activations (re-bake gun after 7th full activation)
- 13 mm photocathode, but use only center portion, 5 mm dia.
- Extract ~ 2000 Coulombs per year
- Beam current ~ 100uA, laser 0.5mm dia., lifetime: 100 - 200 C, $1x10^5$ C/cm^2

Gun Technology

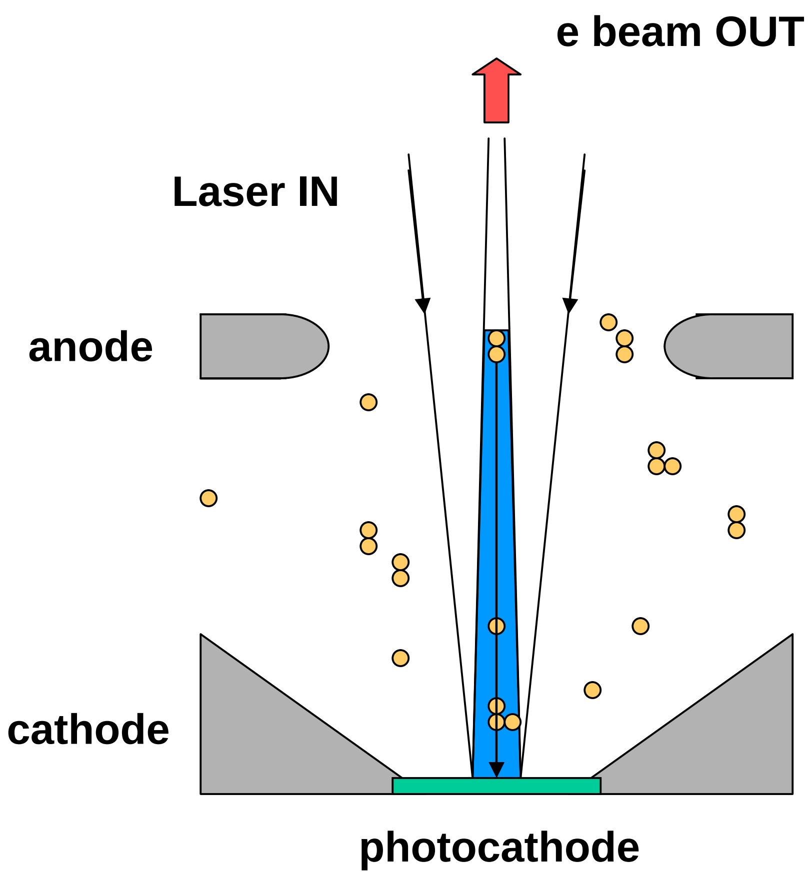
Vent/Bake Guns: need improvement

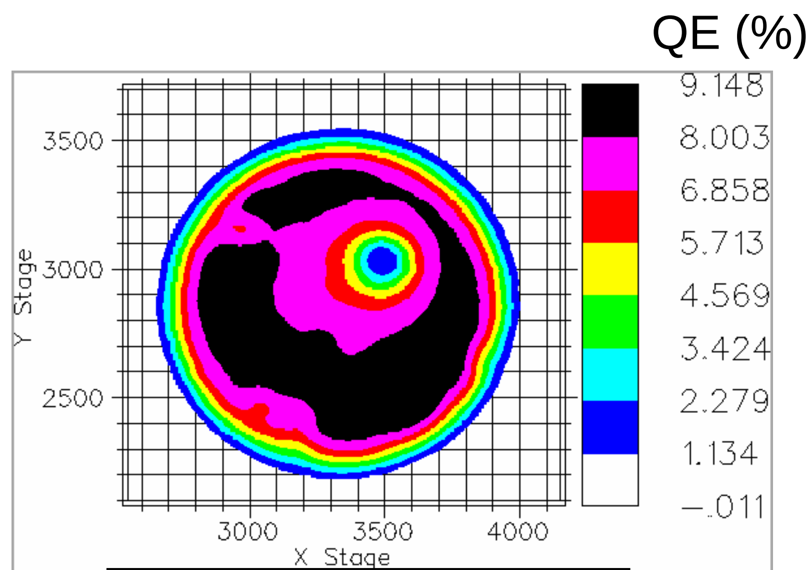
- Difficult to meet demands of approved high current/high polarization parity-violation experiments like PRex (100uA) and Qweak (180uA and 1-year duration)
- Our vent/bake guns can provide only ~ 1 week operation at 180uA
- 12 hours to heat/reactivate, four days downtime to replace photocathode

Design Goal for New Gun: One Month Uninterrupted Operation at 250uA and 85% polarization, One Shift to Replace Photocathode

What limits photogun lifetime?

Imperfect Vacuum and Ion Backbombardment



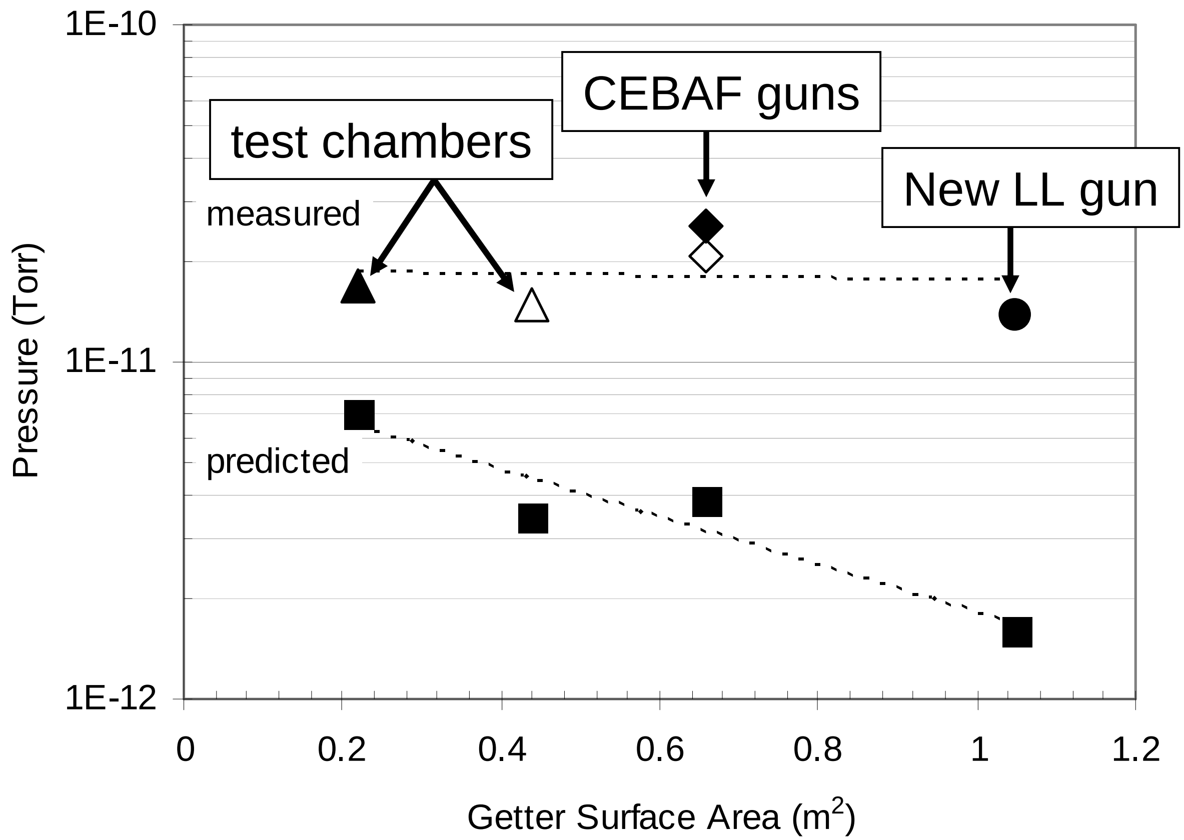


QE scan of photocathode

Note, other factors can limit lifetime: Field emission, photocathode material, laser wavelength, laser radial position on photocathode, beam optics, gun voltage, gap size, …..

Improving Gun Vacuum

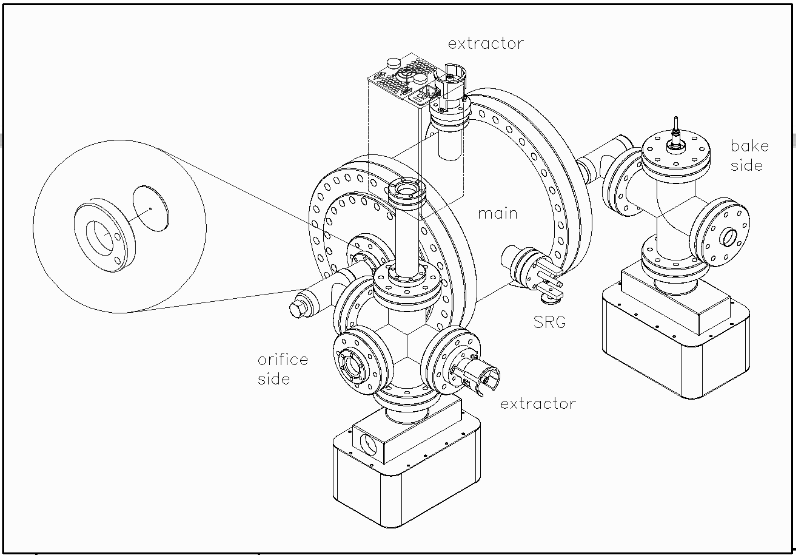
$$\text{Ultimate Pressure} = \frac{\text{Outgassing Rate x Surface Area}}{\text{Pump Speed}}$$



How to explain this discrepancy?

- Outgassing rate higher than assumed "standard" value; 1×10^{-12} Torr·L/s·cm^2?
- NEG pump speed smaller than SAES says?

Measured pressure always much greater than predicted



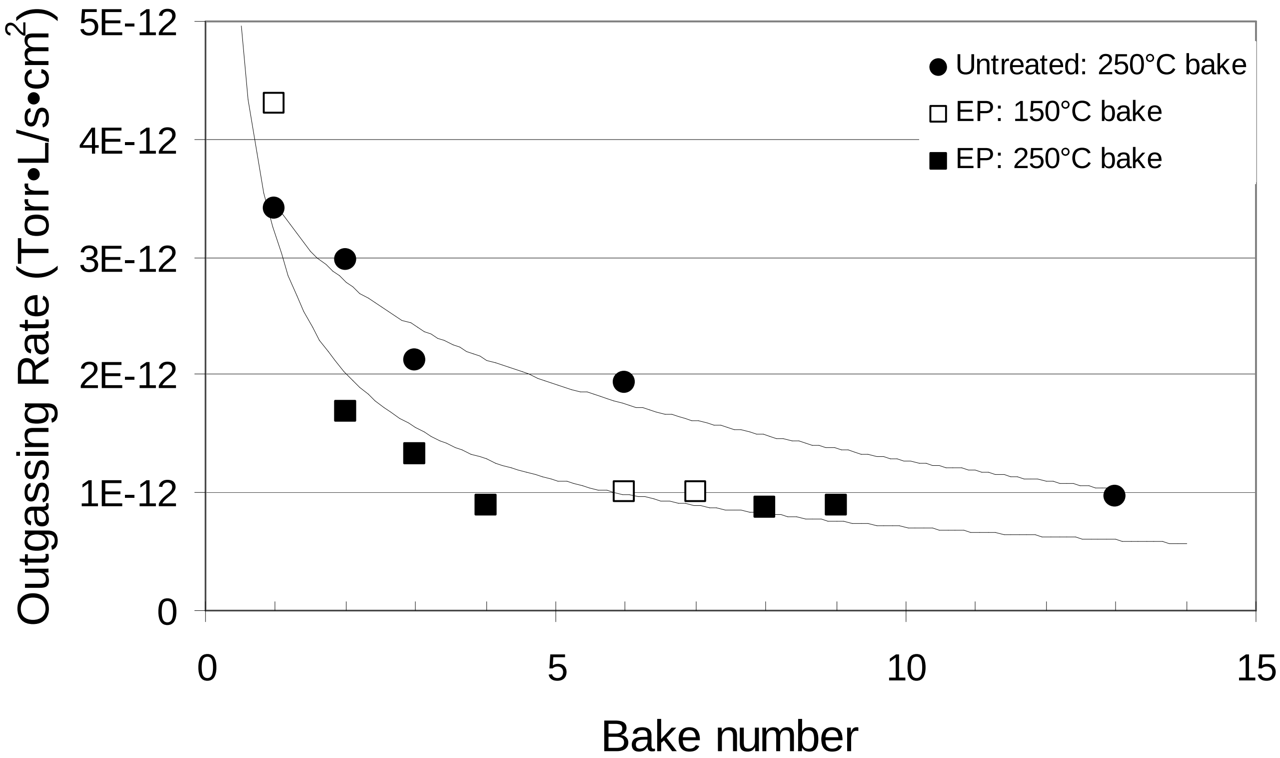
Outgassing Rate

- Orifice and Rate of Rise Methods
- Studied 304, 316L and 6061 Al
- Degreasing/solvent cleaning vs electro-polishing/vacuum firing at 900C

	Preprocessing				In situ bake parameters		Outgassing Rate (Torr·L/s·cm²)	
Chamber	t(h)	T(°C)	EP	Surface roughness	t(h)	T(°C)	Orifice Method	Rate of Rise Method
Old 304			no	3.7 µm	400	250	9.7×10^{-13}	1×10^{-12}
New 304			no	3.7 µm	180	250	1.9×10^{-12}	2.5×10^{-12}
EP 304	4	900	yes	2.1 µm	30 then 90	150 250		8.9×10^{-13}

"Characterization of the CEBAF 100 kV DC GaAs Photoelectron Gun Vacuum System," M.L. Stutzman, et al., Nucl. Instrum. Meth. A, 574 (2007) p. 213-220

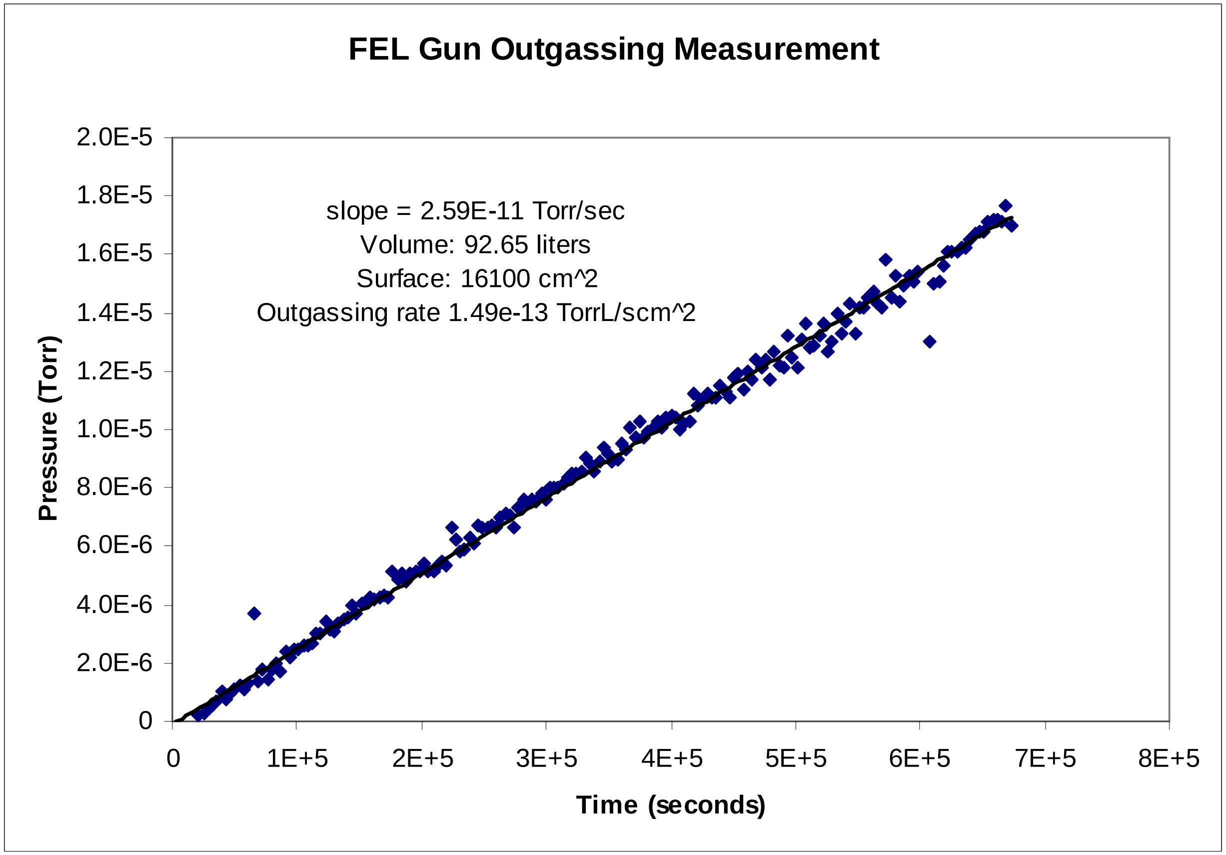
Benefit of EP and Vacuum Firing



- Electropolishing and vacuum firing provides low rate with fewer bakes
- Extremely low values (e.g., 10^{-14} to 10^{-15}) reported in literature elude us
- Conclusion: We have the "industry-standard" outgassing rate ~ 1×10^{-12} Torr·L/s·cm²

Recent High Temperature Bake of JLab FEL Gun

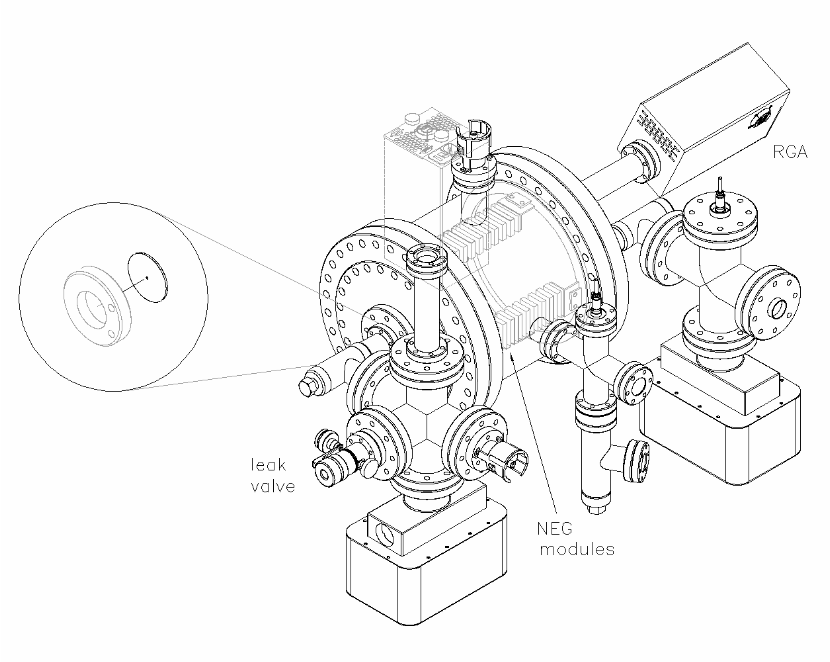
316 LN Stainless Steel, Baked at 400°C for 10 days
Vacuum inside, hot air outside, Strip heaters instead of hot air guns
Outgassing rate: 1.49×10^{-13} Torr L/s cm^2

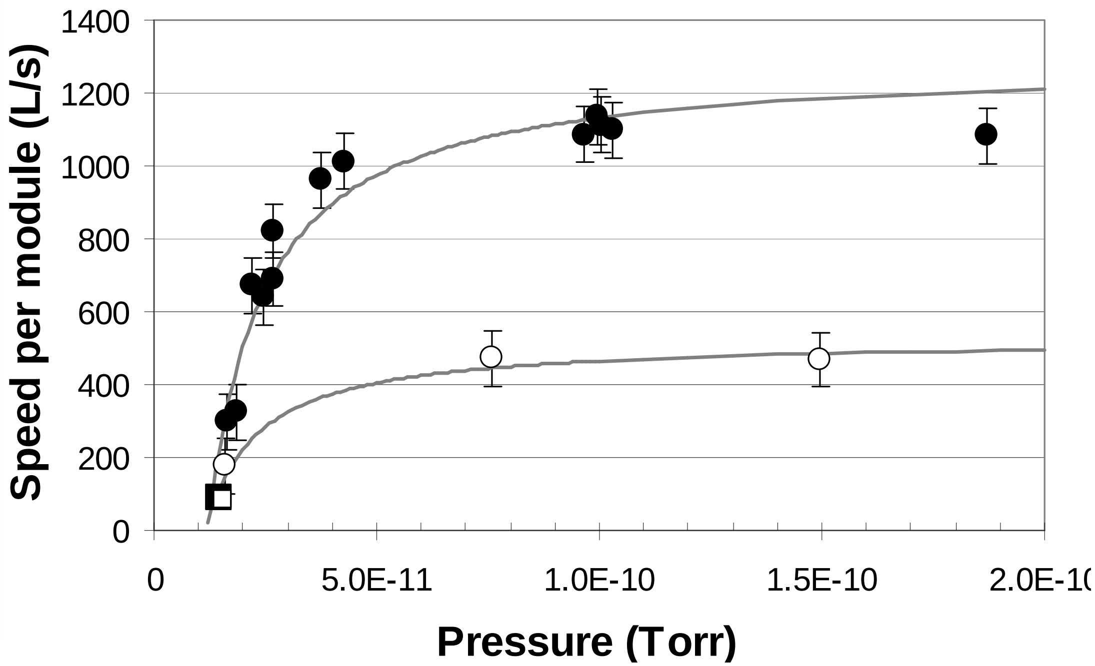


Lessons for CEBAF?

- We should have vacuum fired our end flanges
- Welding introduces hydrogen
- 250C for 30 hours not adequate

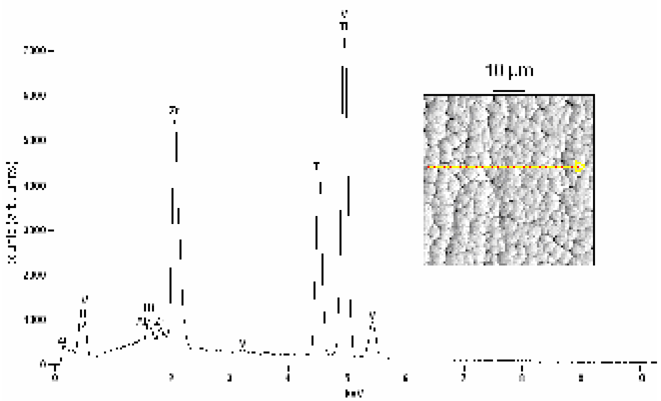
NEG Pump Speed

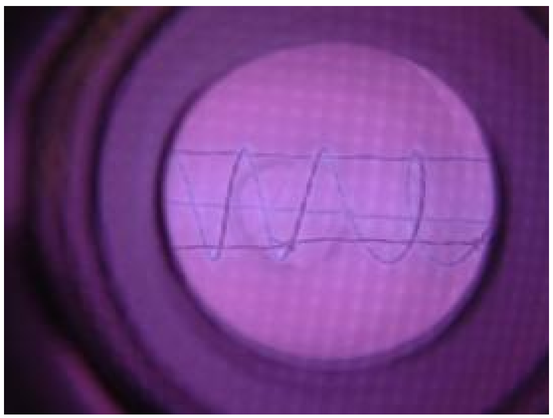


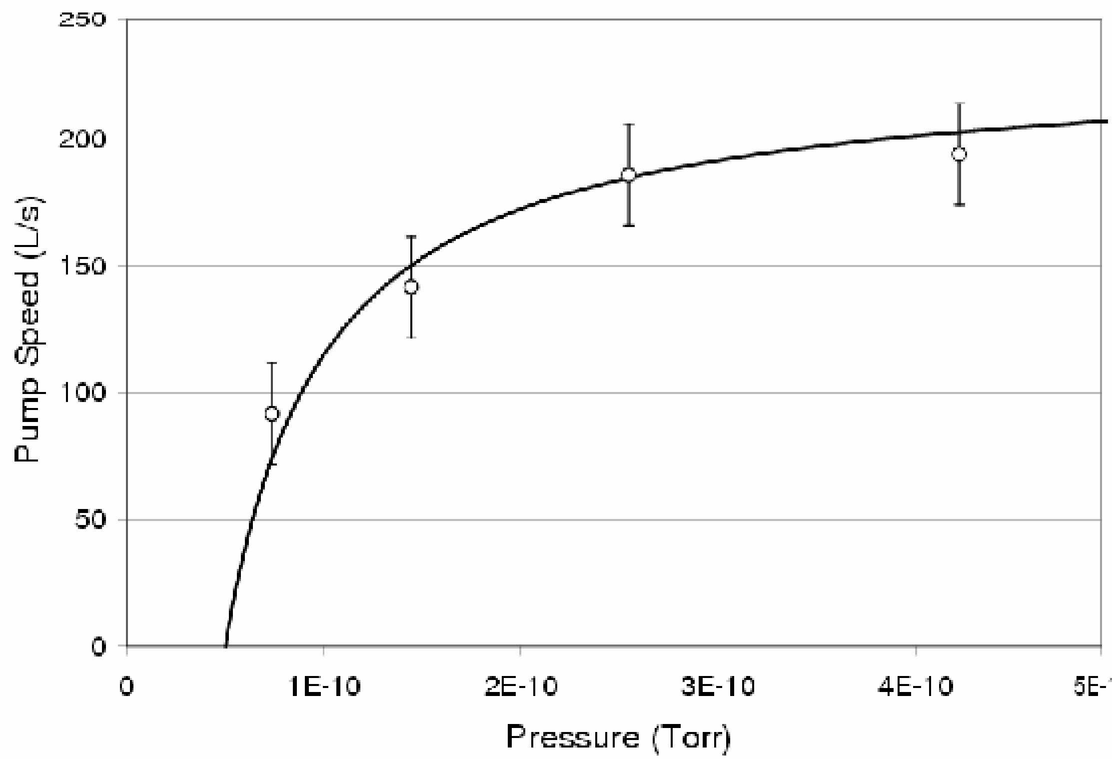


- Full NEG activation better than passive activation via bake
- NEG pump speed very good, at least at high pressure
- Conclusion: Can't explain reduced pump speed at low pressure – a real effect? More likely an indication of gauge limitations

NEG Coating

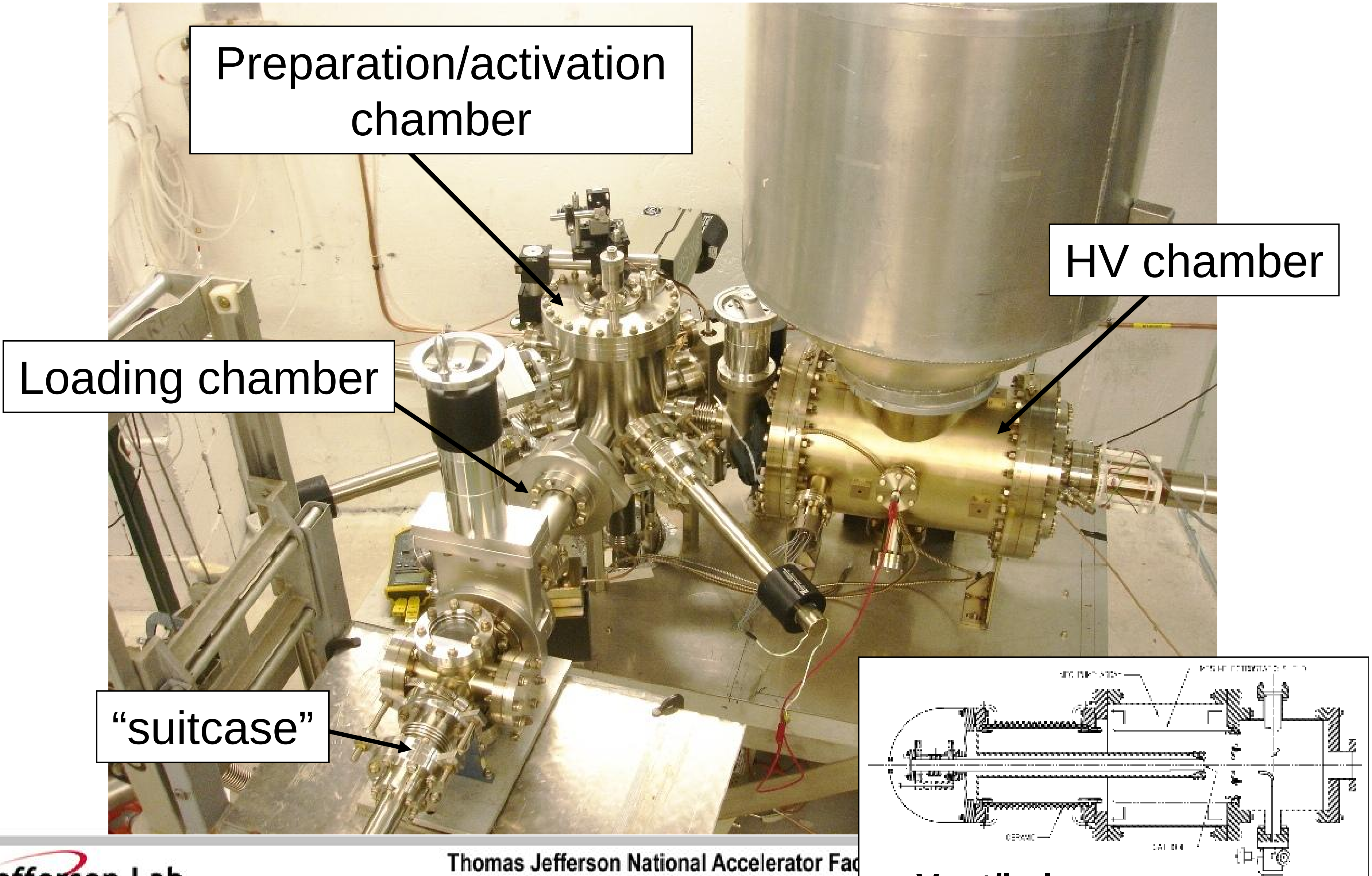






NEG coating turns a gas source into a pump
~0.02 L/s·cm^2 : Modest pump speed can be improved

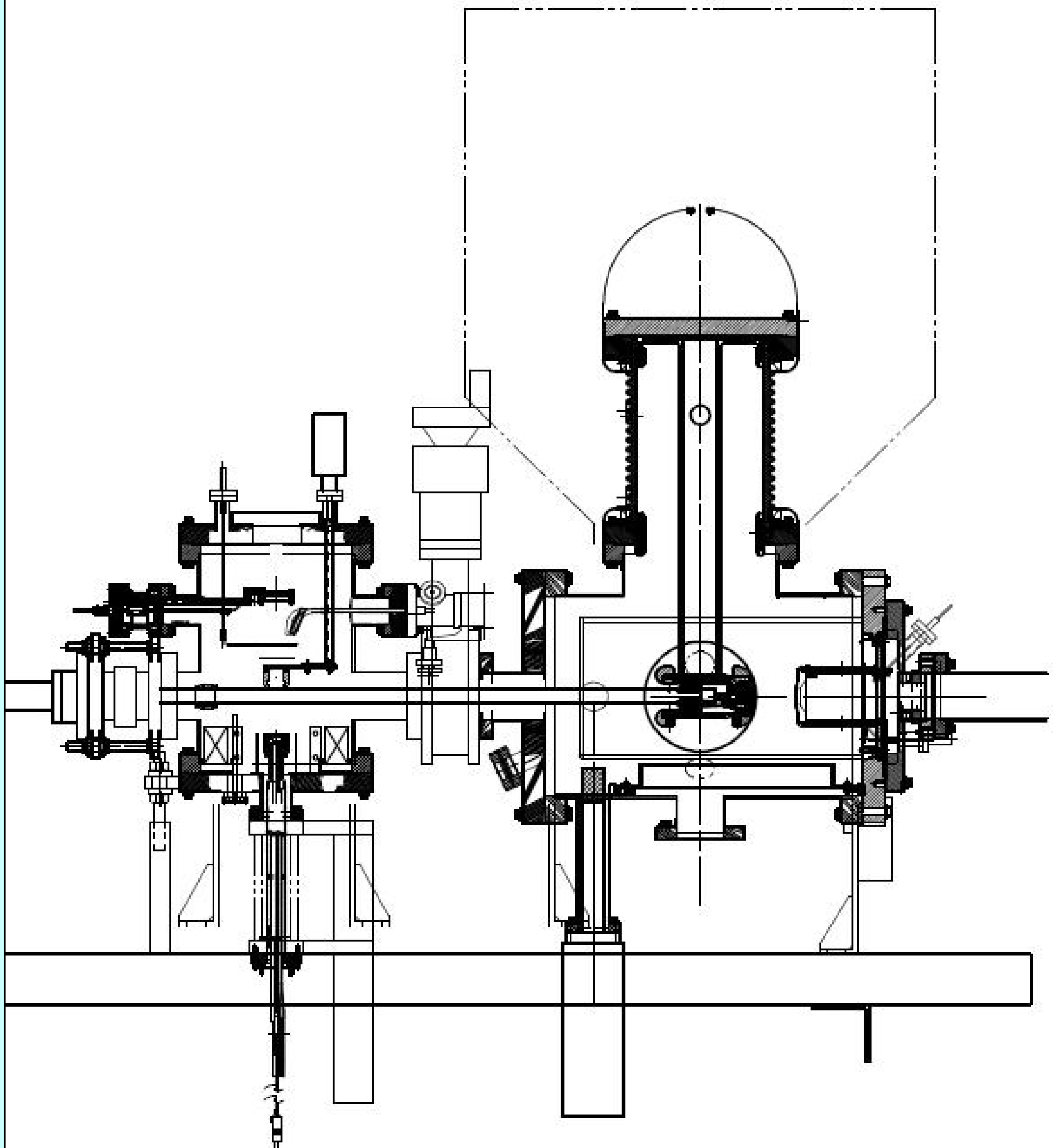
New CEBAF load-locked gun



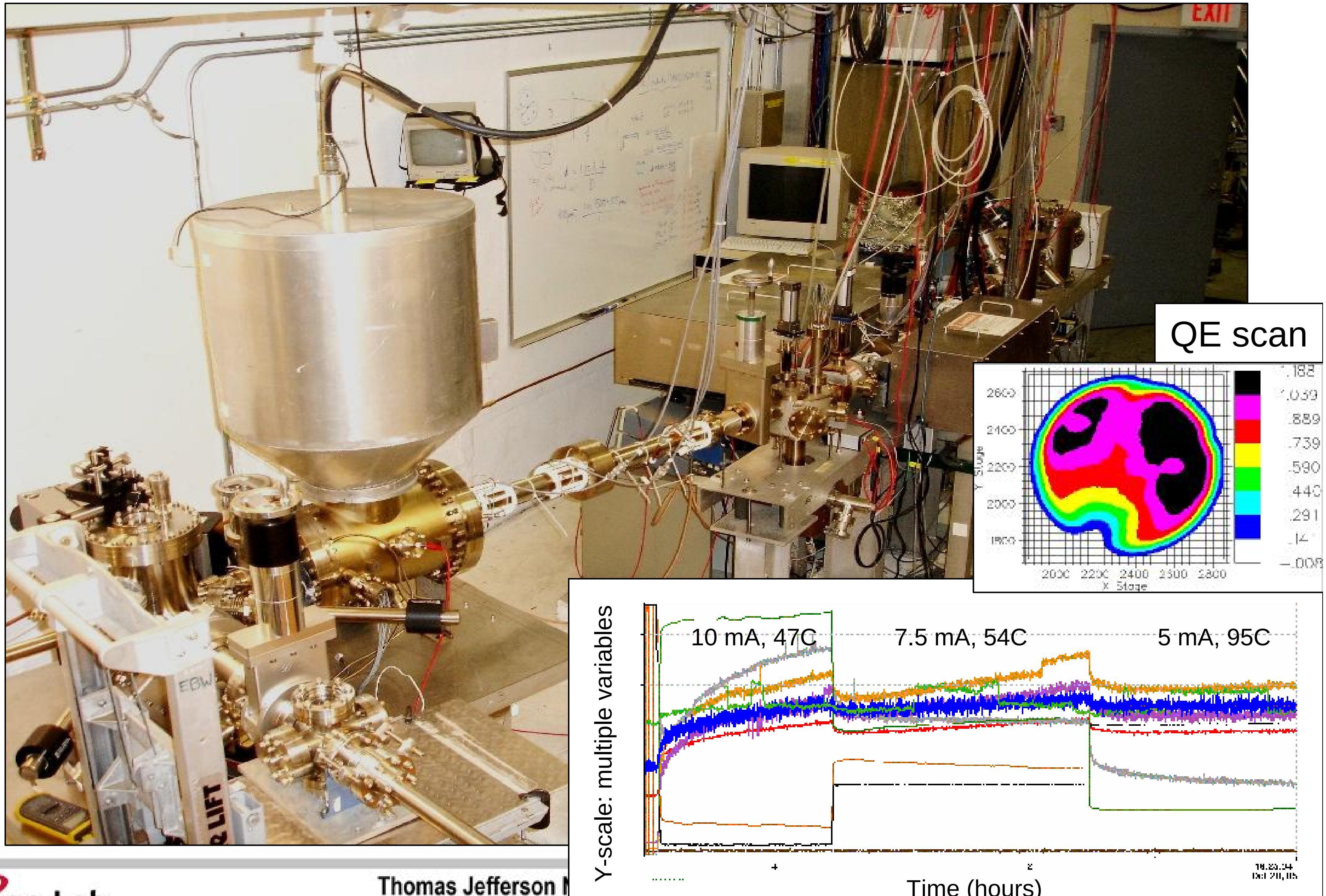
Vent/bake gun

Key Features:

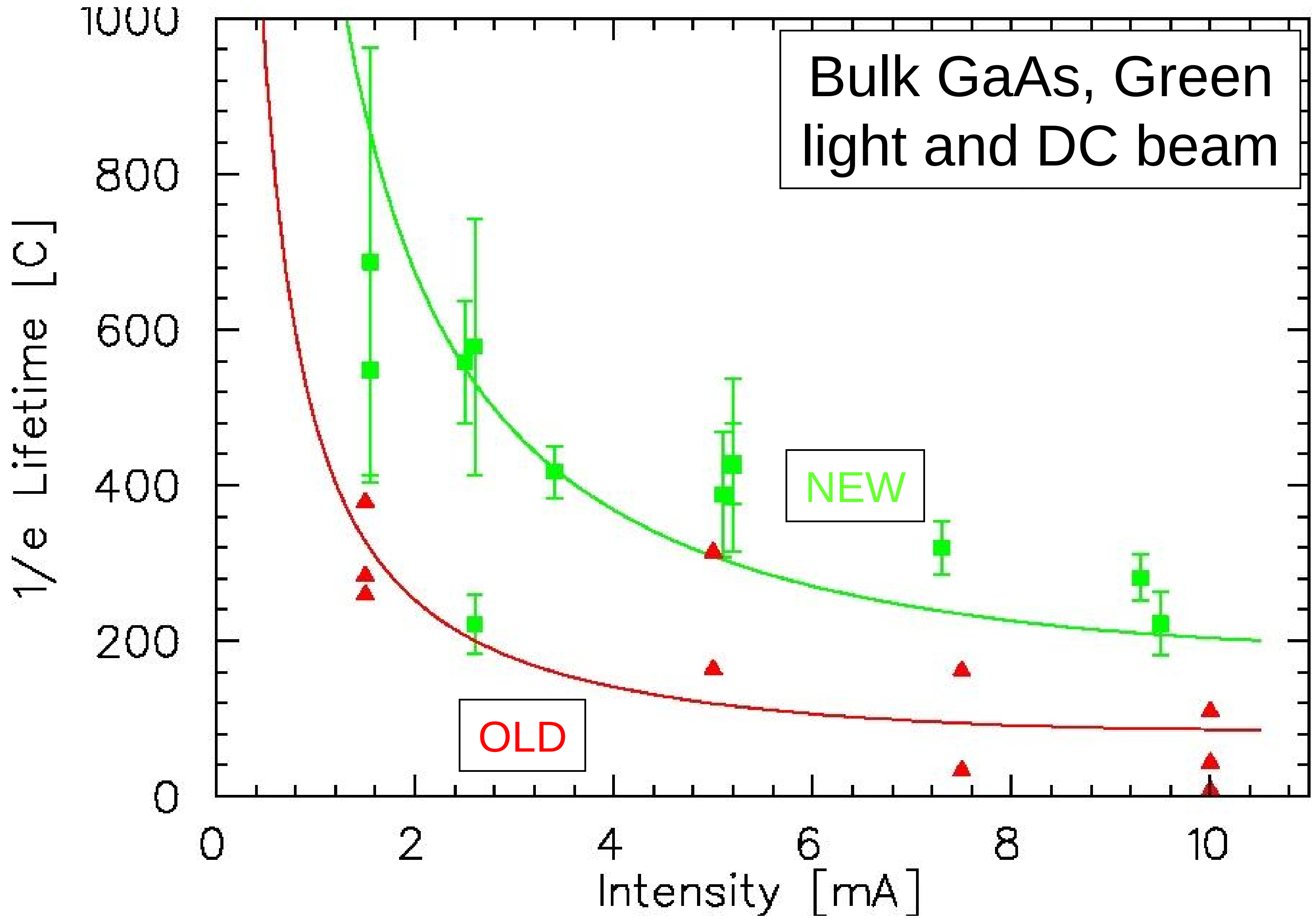
- Smaller surface area
- Electropolished and vacuum fired to limit outgassing
- NEG-coated
- Never vented
- Multiple pucks (8 hours to heat/activate new sample)
- Suitcase for installing new photocathodes (one day to replace all pucks)
- Mask to limit active area, no more anodizing



Load Locked Gun and Test Beamline



Compare NEW and OLD load locked guns



Vacuum gauges indicated same pressure in both guns, suggesting our gauges don't work below 1.5×10^{-11} Torr

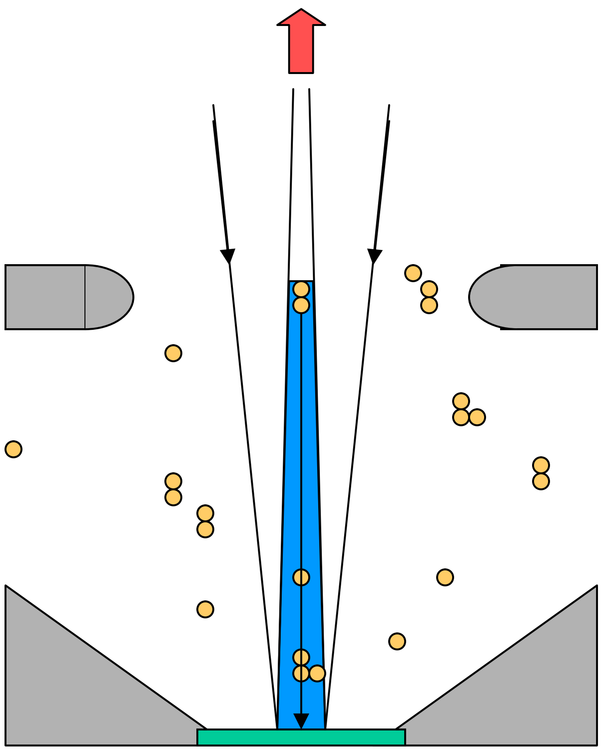
Photogun Lifetime - the best vacuum gauge

"Further Measurements of Photocathode Operational Lifetime at Beam Current > 1mA using an Improved 100 kV DC High Voltage GaAs Photogun," J. Grames, et al., Proceedings Polarized Electron Source Workshop, SPIN06, Tokyo, Japan

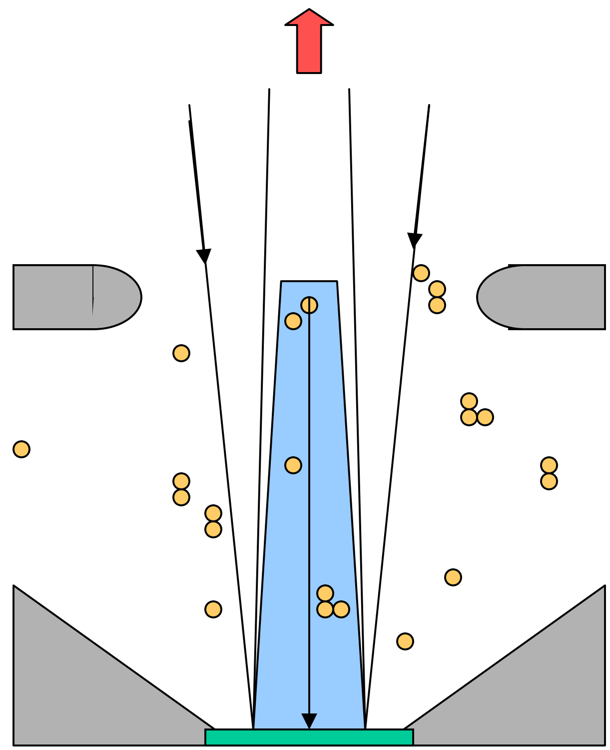
Improve Lifetime with Larger Laser Spot?

(Best Solution – Improve Vacuum, but not easy)

Bigger laser spot, same # electrons, same # ions



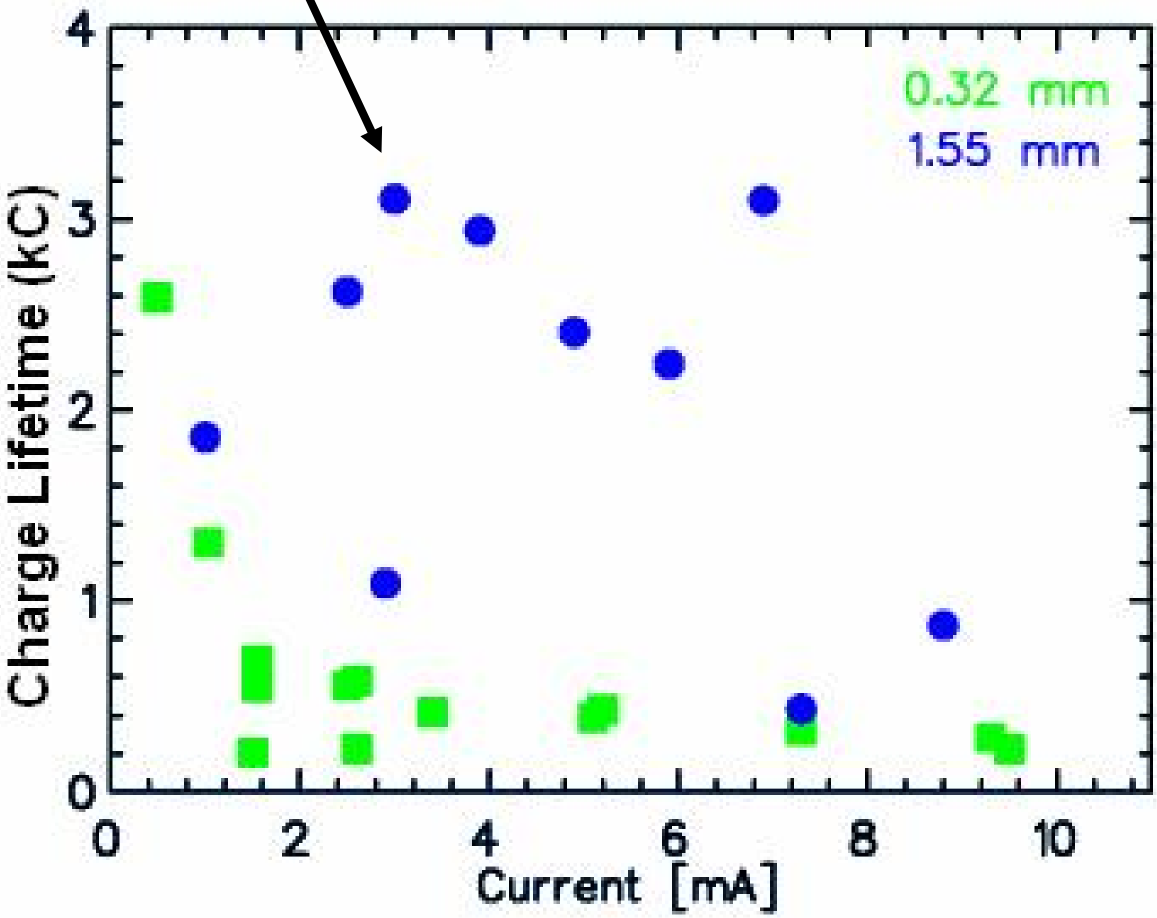
Ionized residual gas strikes photocathode



Ion damage distributed over larger area

Lifetime with Large/Small Laser Spots

Tough to measure large Coulomb lifetimes with only 100-200 C runs!



Factor of 5 to 10 improvement with larger laser spot size

Expectation:

$$\left(\frac{1500}{350}\right)^2 \approx 18$$

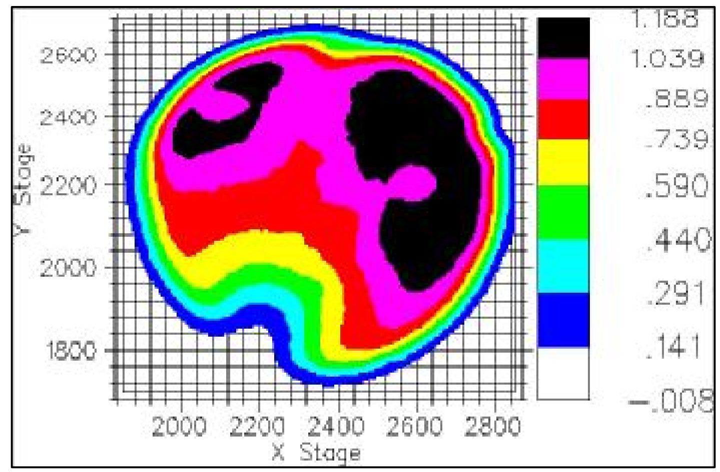
"Further Measurements of Photocathode Operational Lifetime at Beam Current > 1mA using an Improved 100 kV DC High Voltage_GaAs Photogun," J. Grames, et al., Proceedings Polarized Electron Source Workshop, SPIN06, Tokyo, Japan

1mA from High Polarization Photocathode*

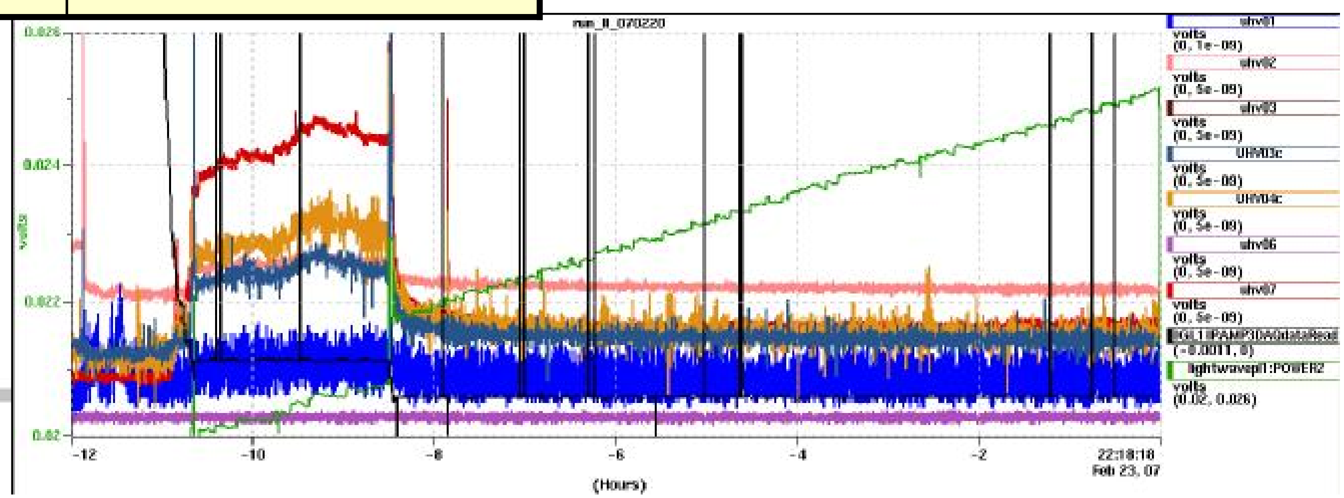
Parameter	Value
Laser Rep Rate	499 MHz
Laser Pulselength	30 ps
Wavelength	780 nm
Laser Spot Size	450 mm
Current	1 mA
Duration	8.25 hr
Charge	30.3 C
Lifetime	210 C
Charge Lifetime	160 kC/cm^2

*** Note: did not actually measure polarization**

High Initial QE



Vacuum signals
Laser Power
Beam Current



How Long Can We Run at 1mA?

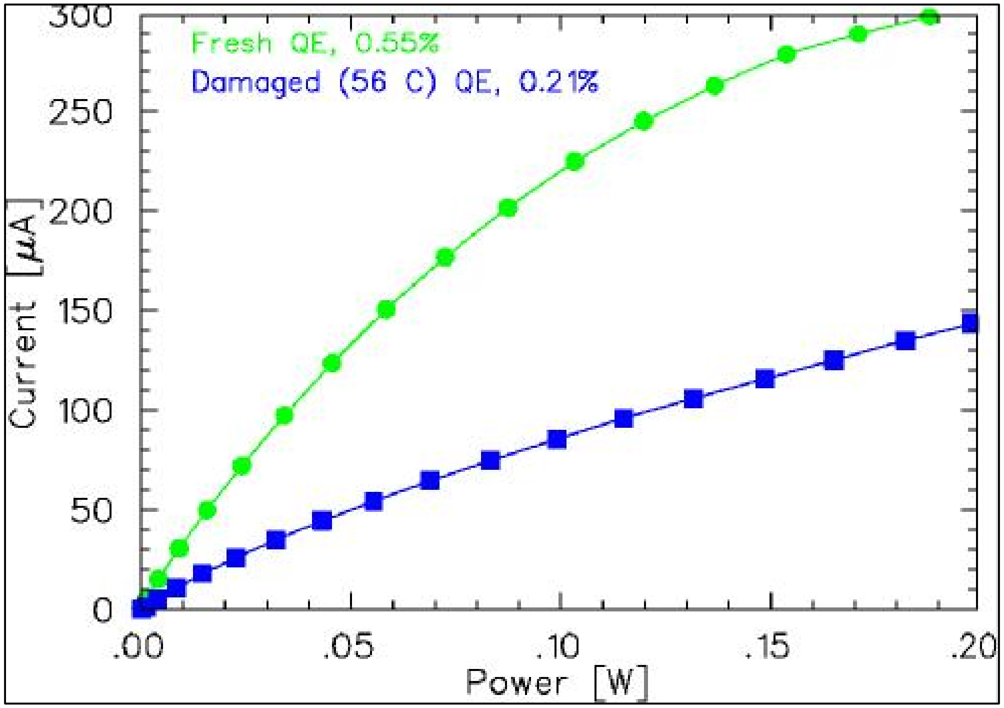
- 1mA operation, 3.6 C/hr, 86 C/day.
- Photocathode with 1% initial QE, 2W at 780nm and gun with 250C charge lifetime (Grames PAC07)
- Initial laser power = 160mW to produce 1mA
- ***Should*** be able to operate at 1mA for 7 days before running out of laser power. Time to move to fresh photocathode spot (10 minutes), swap photocathode (1 hour), heat/reactivate photocathode (8 hours)
- Imagine a 10W laser and 1000C charge lifetime, we should be able to operate at 1mA for 48 days before "doing something"!

How about 25mA?

- 25mA operation, 90 C/hr, 2160 C/day.
- Photocathode with 1% initial QE, Need initial laser power = 4W to produce 25mA
- If gun provides 1000C charge lifetime and you have 25W laser power, you can operate at 25mA for 20 hours before you run out of laser power. Time to move to fresh photocathode spot (10 minutes), swap photocathode (1 hour), heat/reactivate photocathode (8 hours)
- For 100W laser and 10,000C charge lifetime, you can operate at 25mA for 15 days before "doing something".
- To date: ~ 2 Watt laser and 250C lifetime, so we have some work to do….

But QE not constant…

…when surface is damaged or dirty



Surface charge limit, not just a problem for pulsed machines

Future R&D for High Current and High Polarization

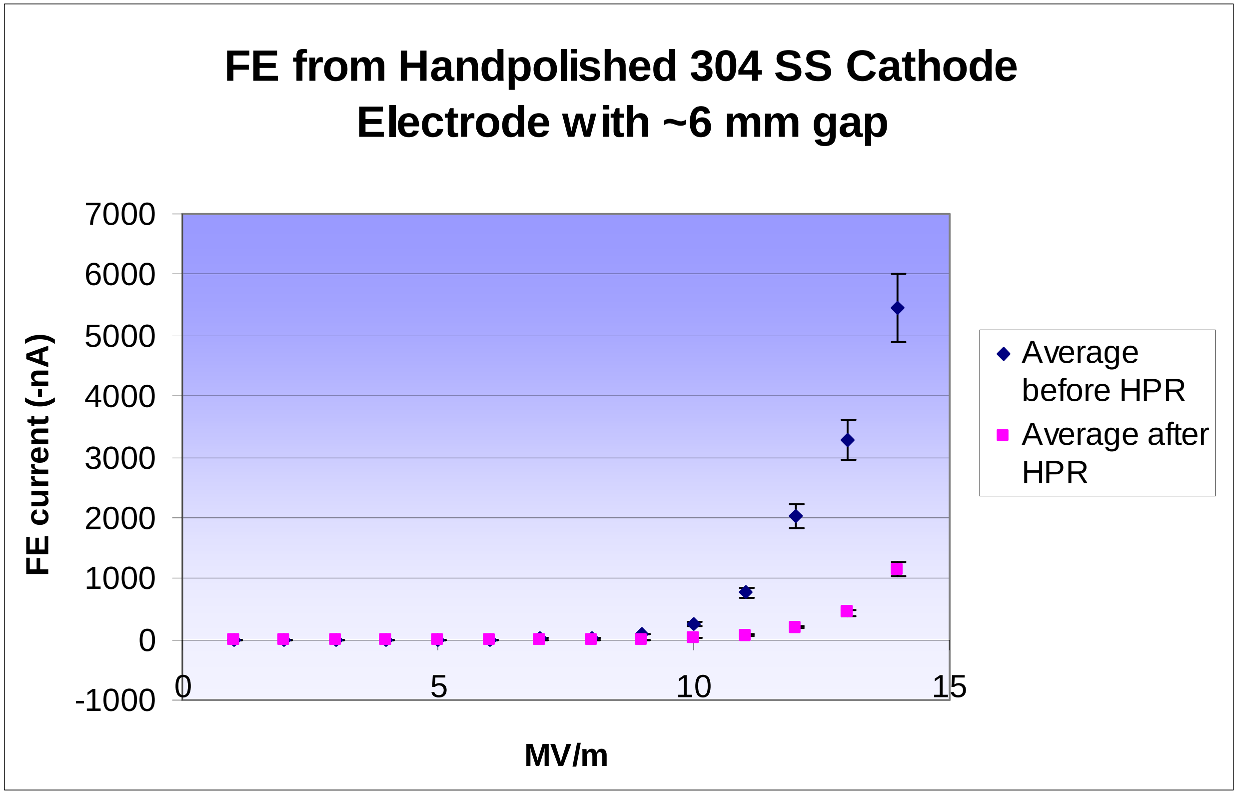
- Install (7/16/07) and Commission Load-Locked gun at CEBAF. Demonstrate improved performance compared to vent/bake guns.
- More High Current Lifetime studies at Gun Test Stand: biased anode (see talk by Grames), increase gun voltage, reduce anode/cathode gap
- High Voltage: eliminating breakdown and field emission (high pressure rinse and coatings)

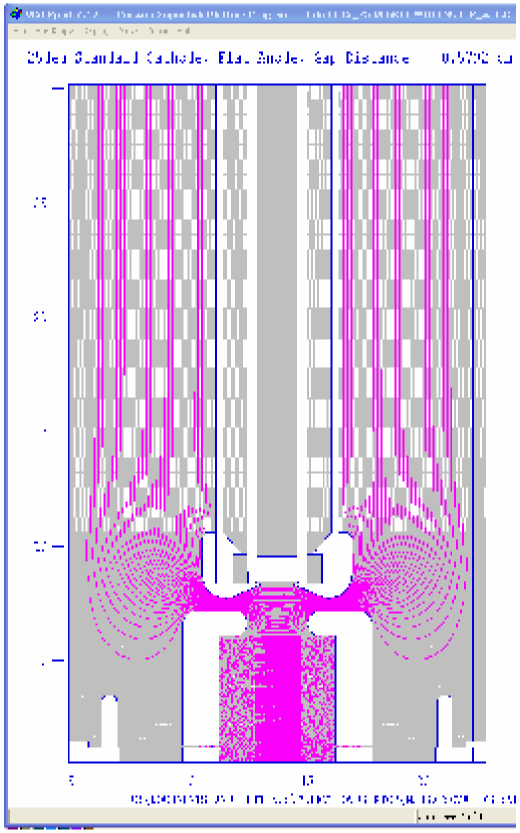
High Pressure Rinsing

Cornell Technique to reduce field emission (B. Dunham ERL07)

Recent tests at JLab with shaped electrodes support Cornell results

Work of M. Chetsova K. Surles-Law





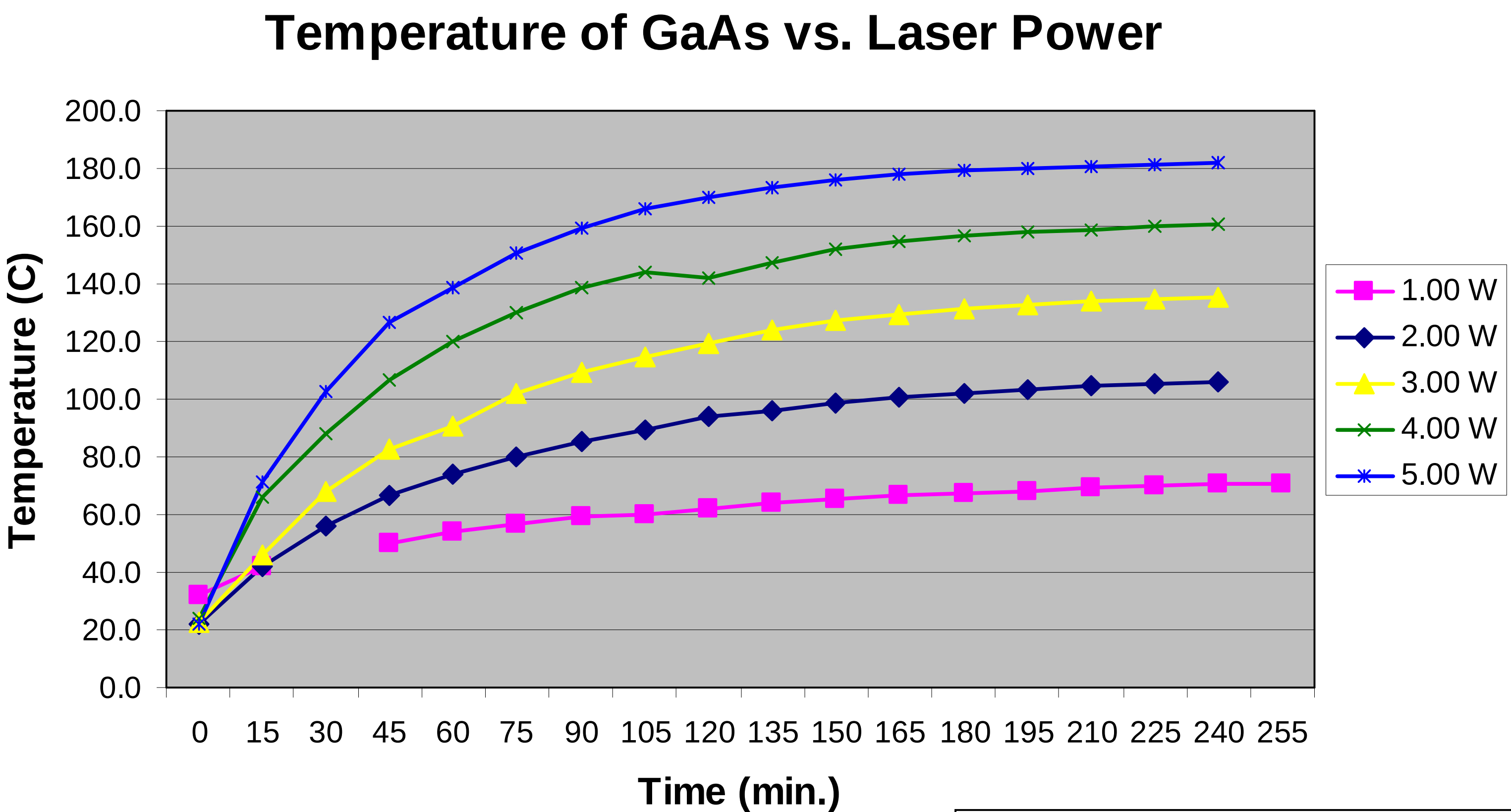
Future R&D for High Current and High Polarization

- Cathode/anode design: managing ALL of the beam. Like to implement multivariate optimization
- How to measure UHV/XHV pressure? Build modified Helmer gauge?
- Surface Charge Limit (QE not constant). What to study?
- Spintronics photocathodes, half-metals, high polarization and QE>>1%?
- Photocathode Cooling: needed when laser power exceeds ~ ~~1W~~

0.5 W

Photocathode Heating

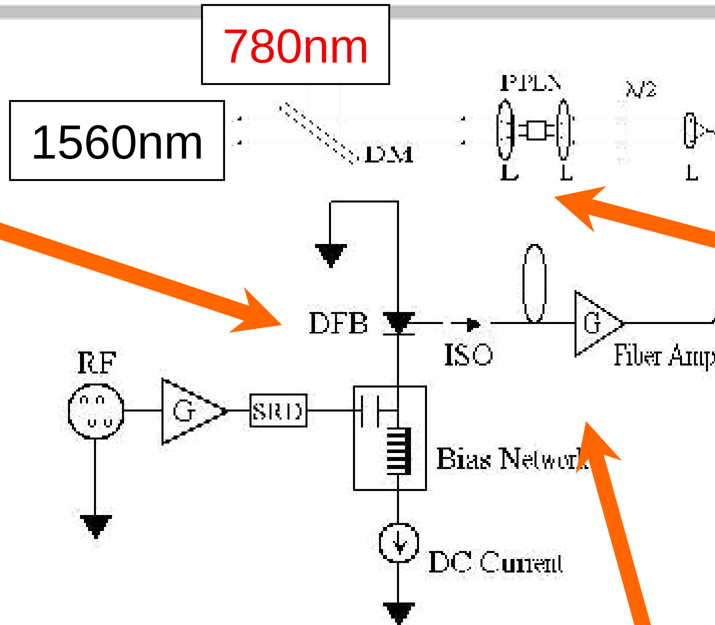
Experiment using 15 mm square GaAs photocathode, indium soldered to “short” stalk, and secured with tantalum cup



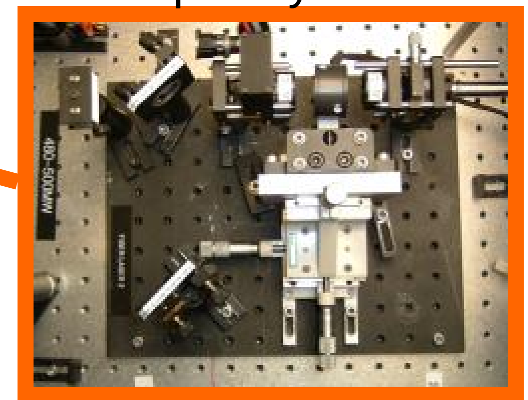
Work by Deborah Mansour

Fiber-Based Drive Laser

Gain-switched seed

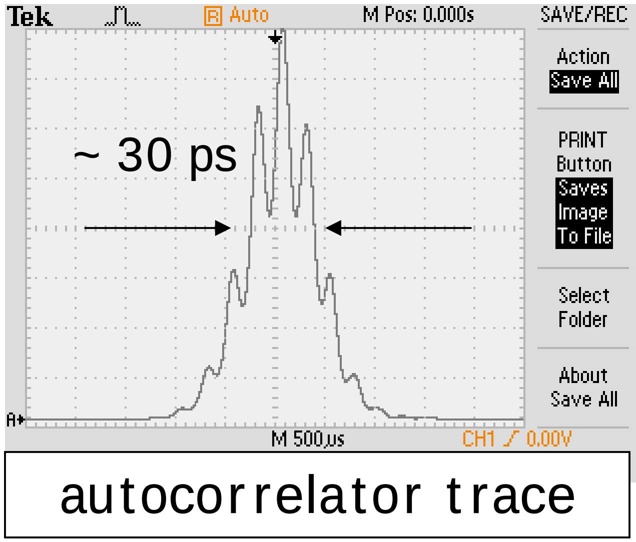


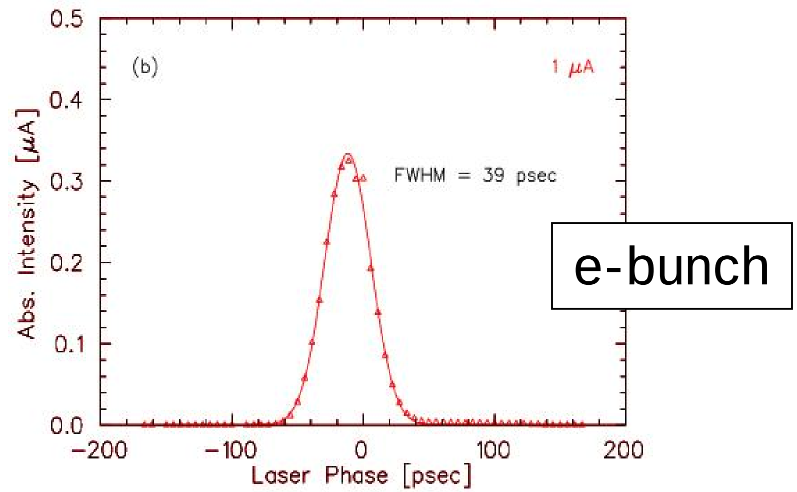
Frequency-doubler

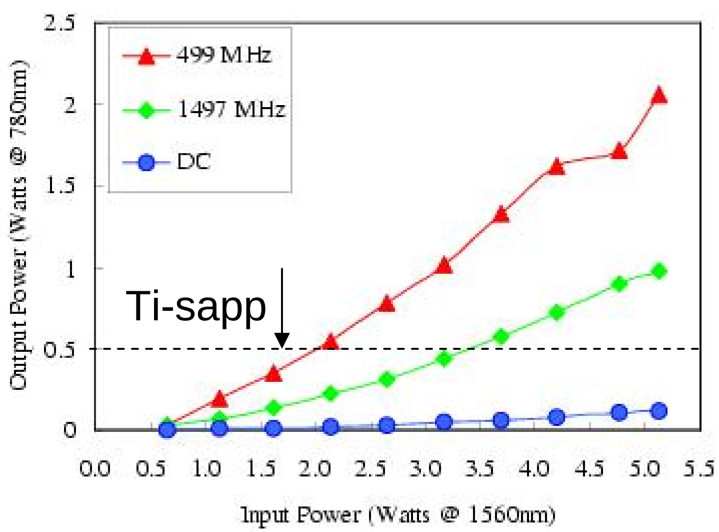


ErYb-doped fiber amplifier

Fiber-based Drive Laser

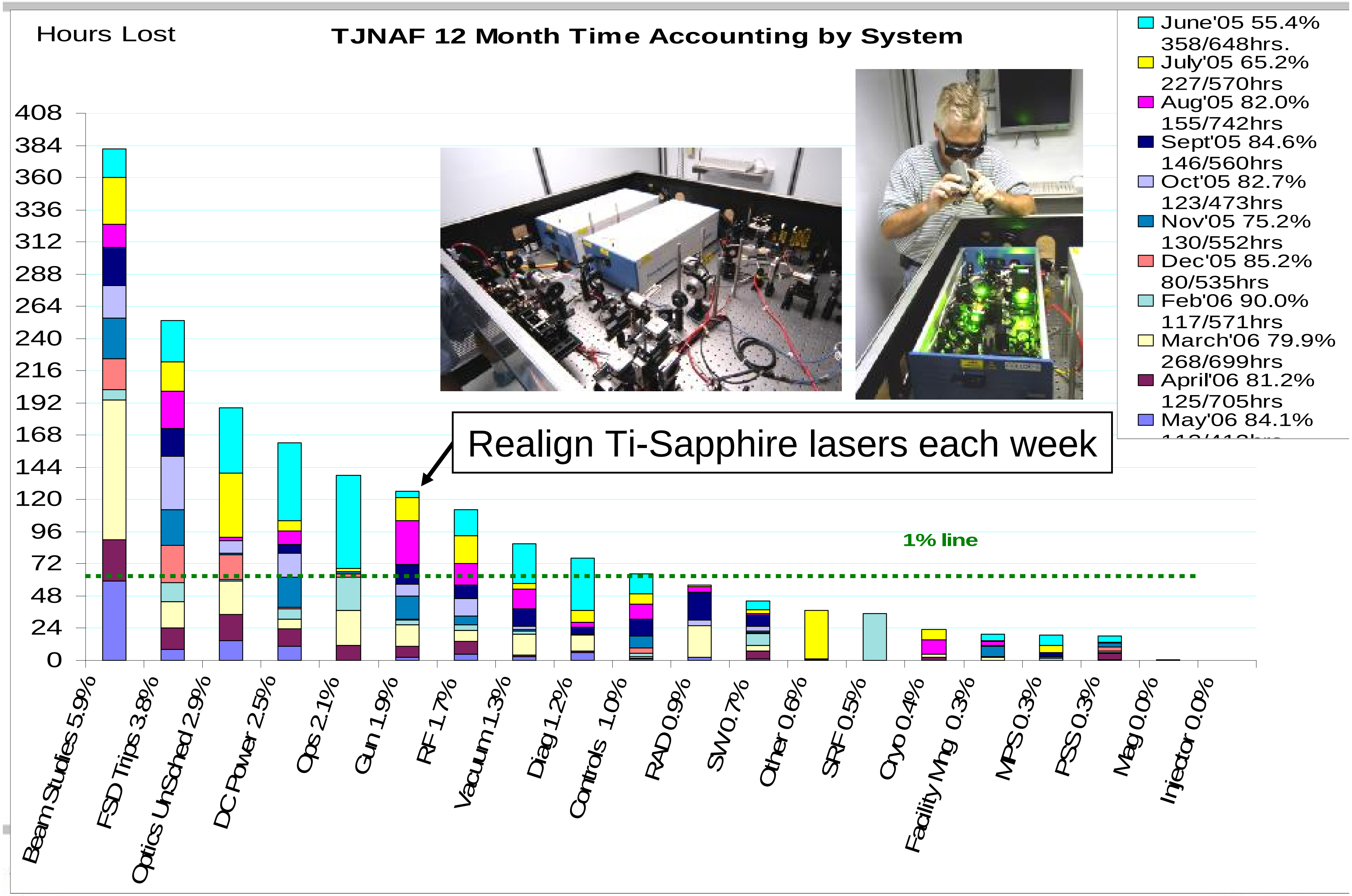




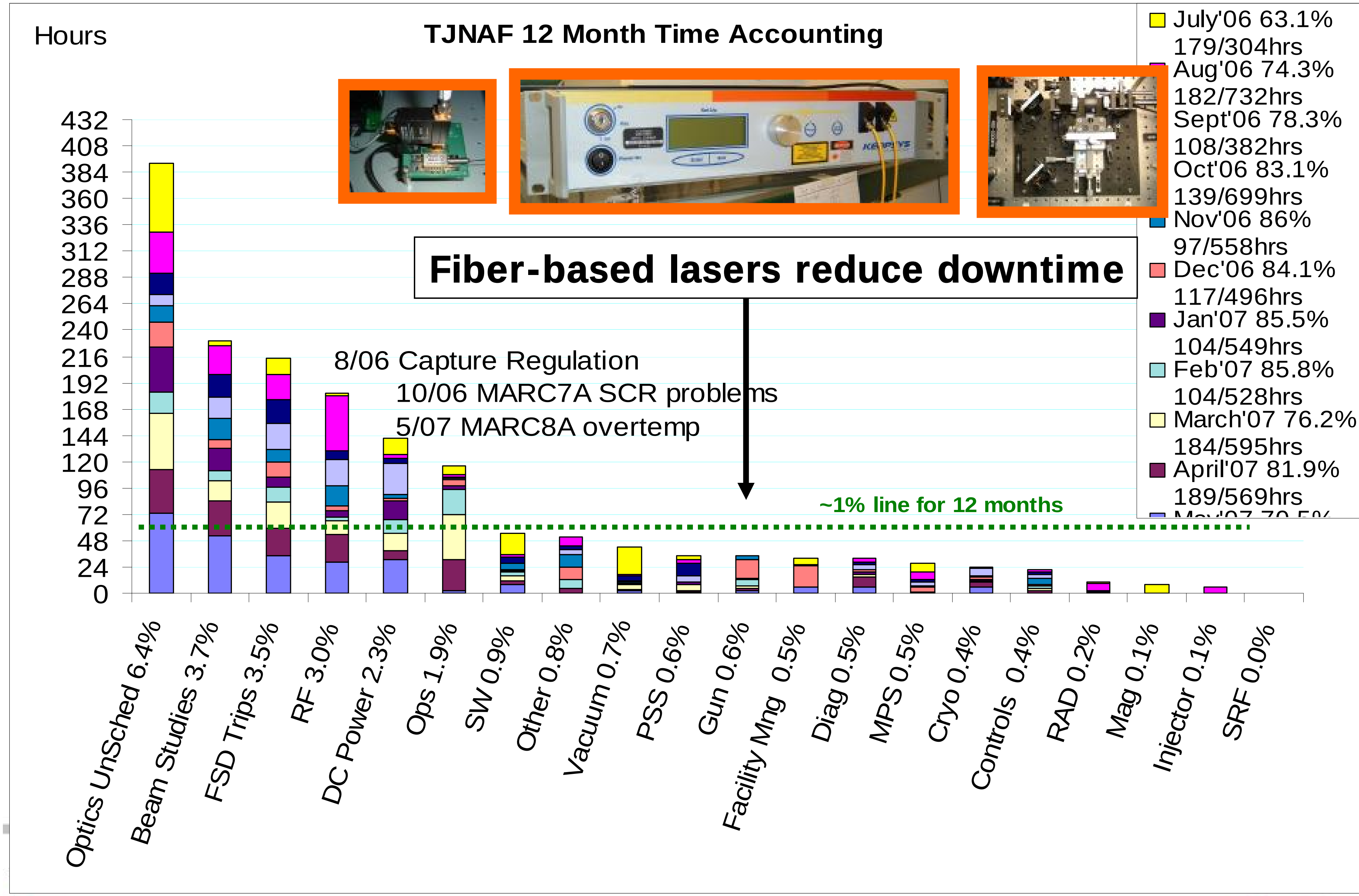


- CEBAF's last laser!
- Gain-switching better than modelocking; no phase lock problems, no feedback
- Very high power
- Telecom industry spurs growth, ensures availability
- Useful because of superlattice photocathode (requires 780nm)

Accelerator Downtime FY05Q4 – FY06Q3



Accelerator Downtime FY06Q4 – FY07Q3



Routine Parity Violation Experiments?

“Parity Quality” = identical beam properties in both helicity states

Parity-Quality Beam Requires:

- Long lifetime photogun (i.e., uniform QE, no “hole”)
- Eliminate electronic ground loops: isolate electronics
- Feedback loops; charge and position asymmetry
- Specific requirements for each experiment; e.g., 31 MHz pulse repetition rate, 250 Hz helicity flipping, beam halo < , etc.,
- Properly aligned laser table, pockels cell (HAPPEx method)
- Stable injector (especially RF phases)
- Proper beam-envelope matching throughout machine for optimum adiabatic damping
- Set the phase advance of the machine to minimize position asymmetry at target

Meeting Helicity Correlated Beam Specs

Recent “parity” upgrades…

- Remote control of pockels cell x/y position
- Helicity magnets for position feedback
- Fast helicity flipping at 250Hz, to decouple helicity correlated effects from target boiling/density fluctuations

In the works…

- Improved isolation of helicity correlated electronics
- New feedback algorithm. Different correction for +-+- compared to +--+ (new Charge Asymmetry control electronics)

Round Table Discussion Topics: Prospects and Challenges for Polarized e- Sources

- Long operational lifetime at high current demands that we managing **ALL** of the extracted electron beam: need for improved cathode/anode design? Use multivariant optimization technique for cathode/anode design?
- How to best implement photocathode cooling?
- High Voltage Issues beyond 120kV: insulators, managing/eliminating field emission
- Charge Limit: manifestation in pulsed and CW mode. How to eliminate?
- Photocathodes: polarization > 90%, better GaAs-based designs, other photocathodes (e.g., half-metals)?
- Beam dynamics: emittance preservation, laser beam/pulse shaping, eliminating tail on beam micropulse
- Polarized RF gun status: a realizable dream?