Status of High Polarization DC High Voltage GaAs Photoguns

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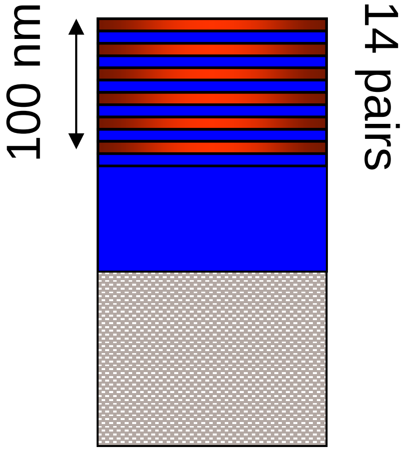
Polarized Electron Beam Requirements:

Good gun

Bake/Vent Guns

Good Photocathode

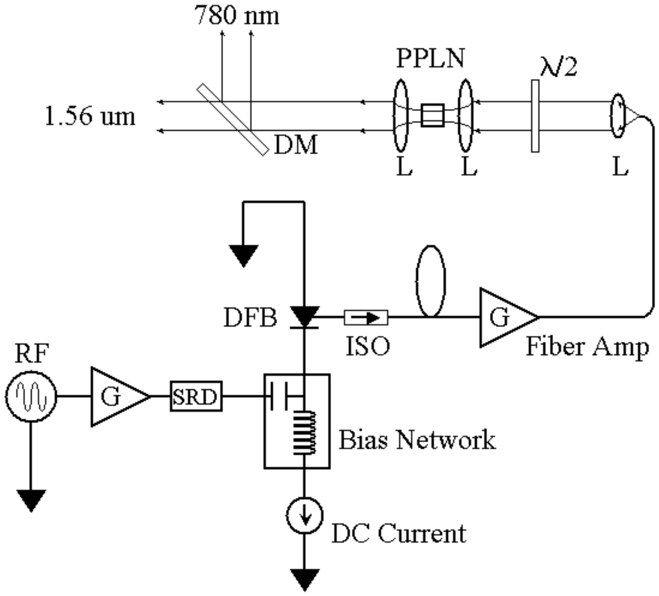
Superlattice GaAs:
Layers of GaAs on GaAsP



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

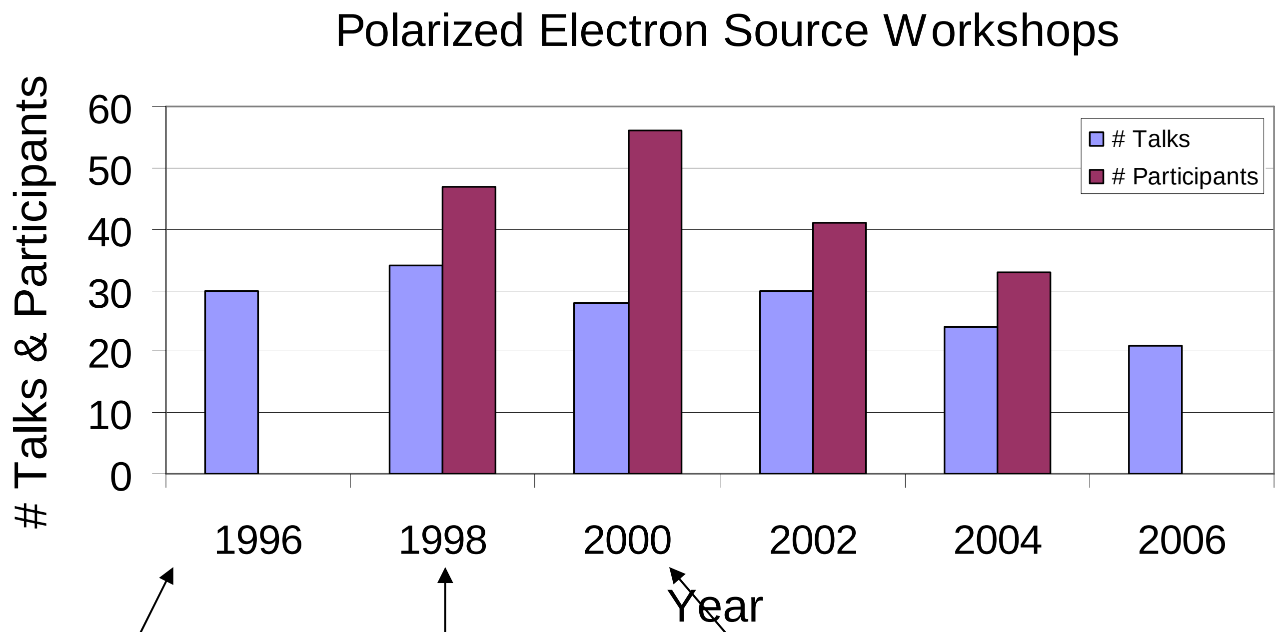
Good Laser

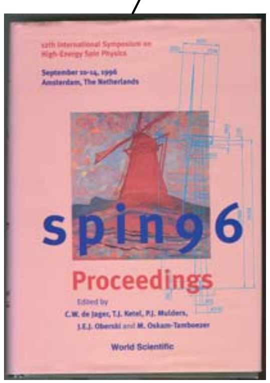
Fiber-based Laser

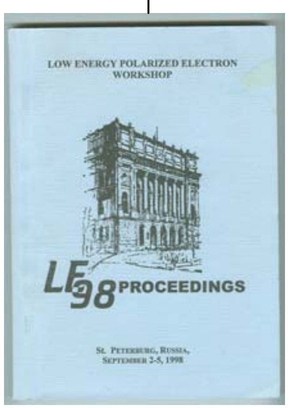


These items exist at many locations, with happy Users worldwide…..

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)

New GaAs-Based Photoinjector Initiatives

Polarized Electron Beam: looking 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)

Recent Developments

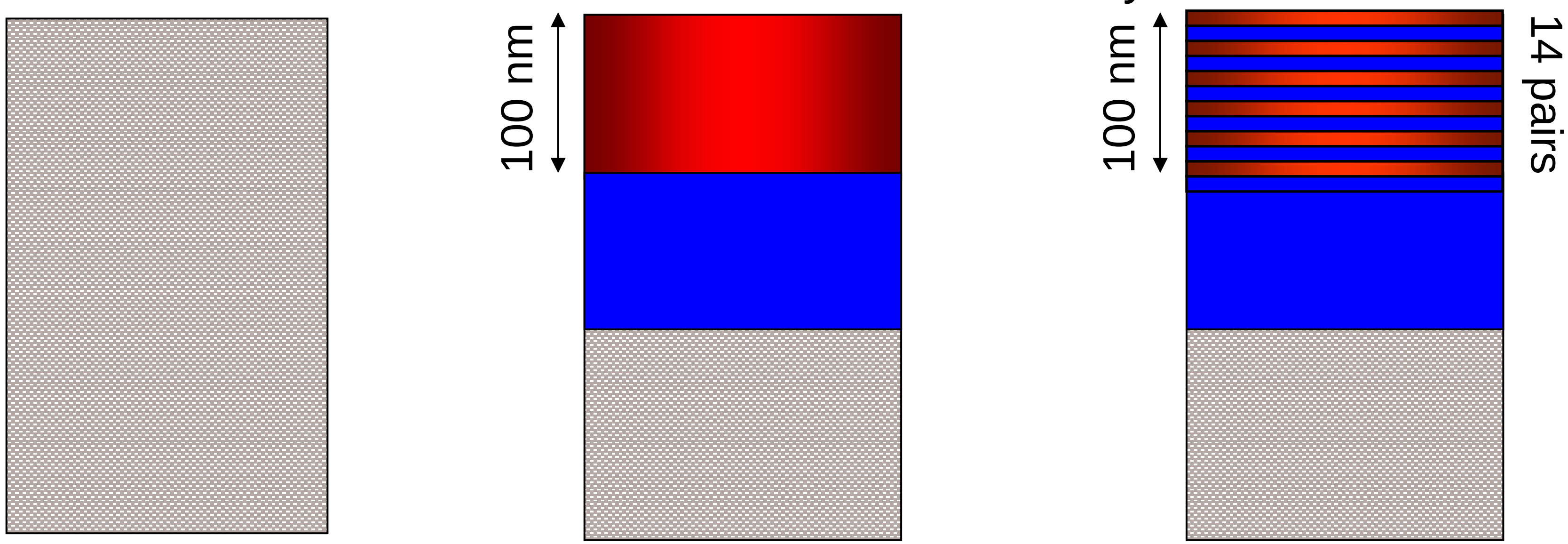
- Commercial strained-superlattice photocathode
  - Consistent 85% polarization, ~ 1% QE
- Fiber-based drive laser
  - Low maintenance, No feedback loops, higher power
- CEBAF load-locked gun
  - Improved vacuum
- High Current R&D
  - Lifetime scaling with laser spot size
  - 1mA sustained operation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

Photocathode Material

Bulk GaAs

Strained GaAs:
GaAs on GaAsP

Superlattice GaAs:
Layers of GaAs on GaAsP



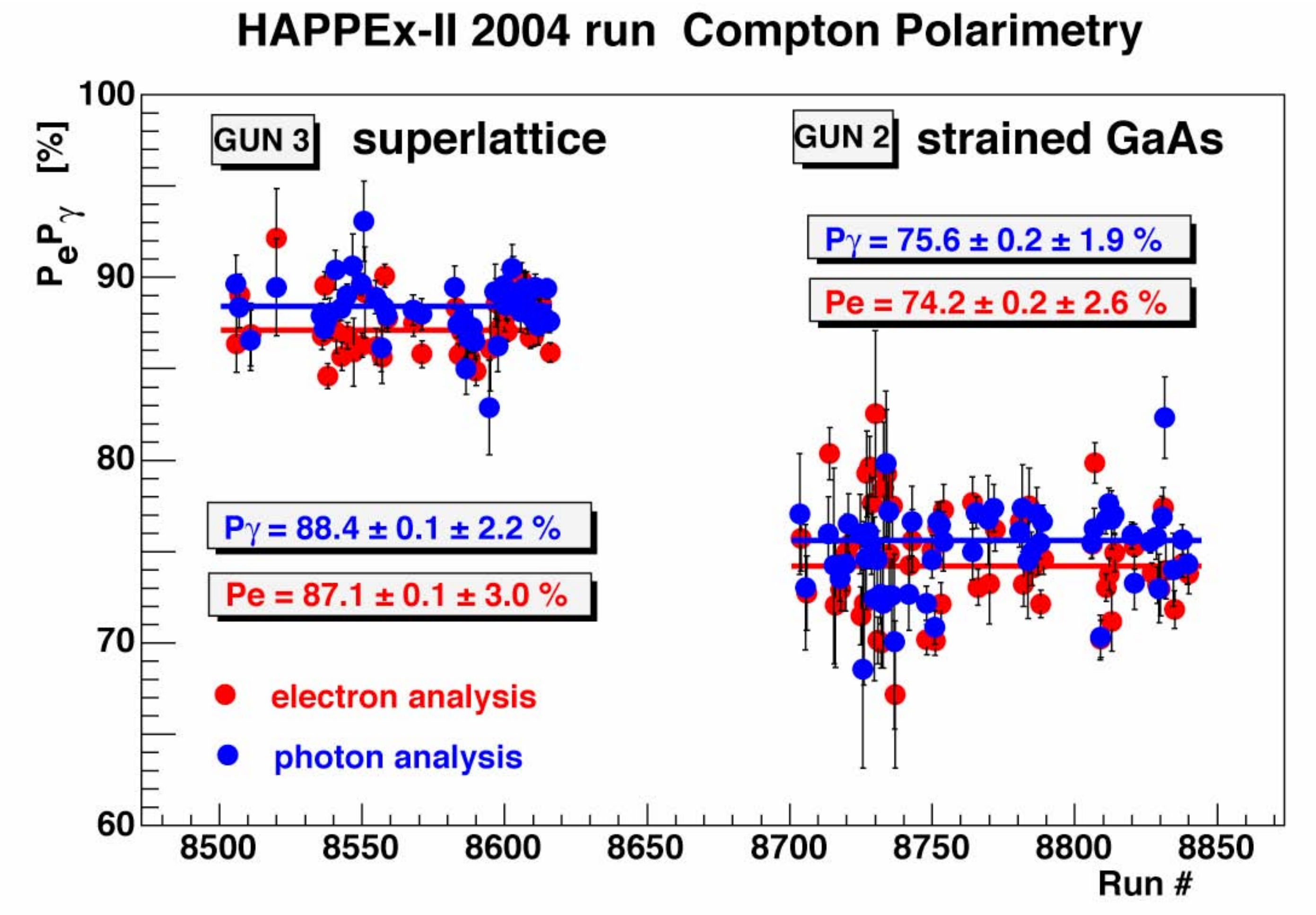
High QE ~ 20%
Pol ~ 35%

“conventional” material
QE ~ 0.15%
Pol ~ 75%
@ 850 nm

No strain relaxation
QE ~ 1%
Pol ~ 85%
@ 780 nm

Both are results of successful SBIR Programs

Significant FOM Improvement



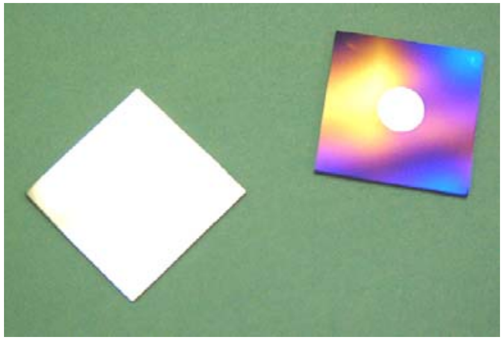
$$\frac{P_{sup.}^{2} I}{P_{str.}^{2} I} = 1.38$$

But we could not operate with long lifetime….

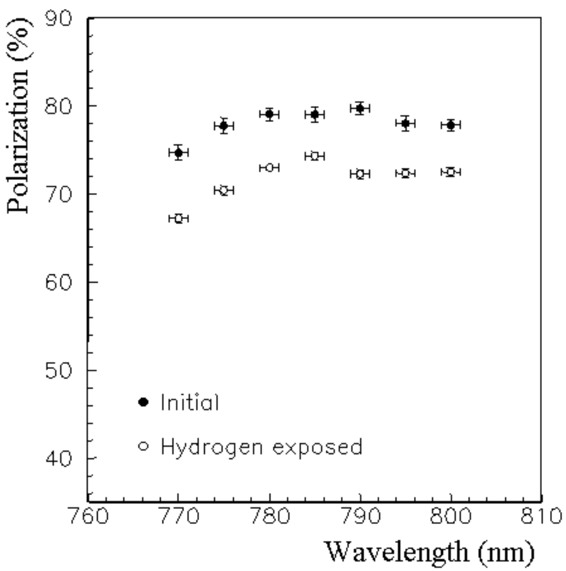
Commercial Superlattice Photocathodes

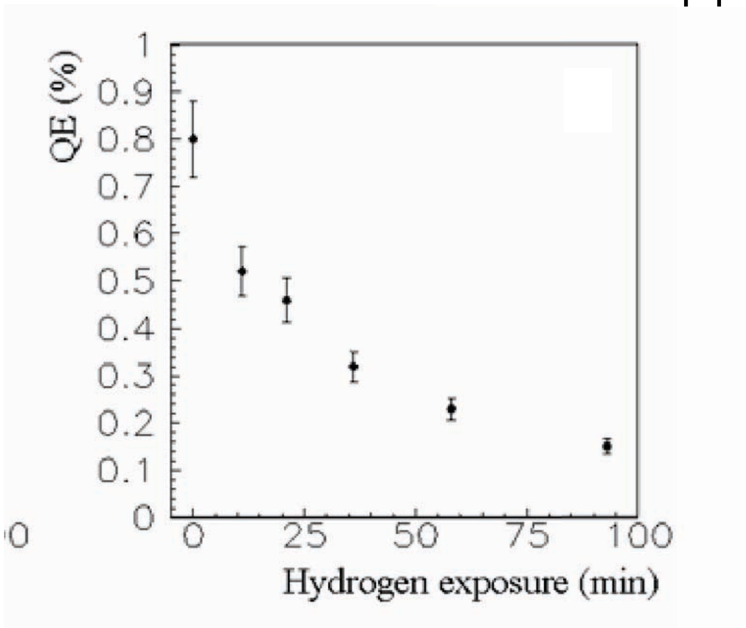
- Success required ~ 1 year of effort
- Cannot be hydrogen cleaned
- Arsenic capped (worked with vendor SVT)
- No solvents during preparation!

M. Baylac et al., "Effects of atomic hydrogen and deuterium exposure on high polarization GaAs photocathodes" PRST-AB 8, 123501 (2005)



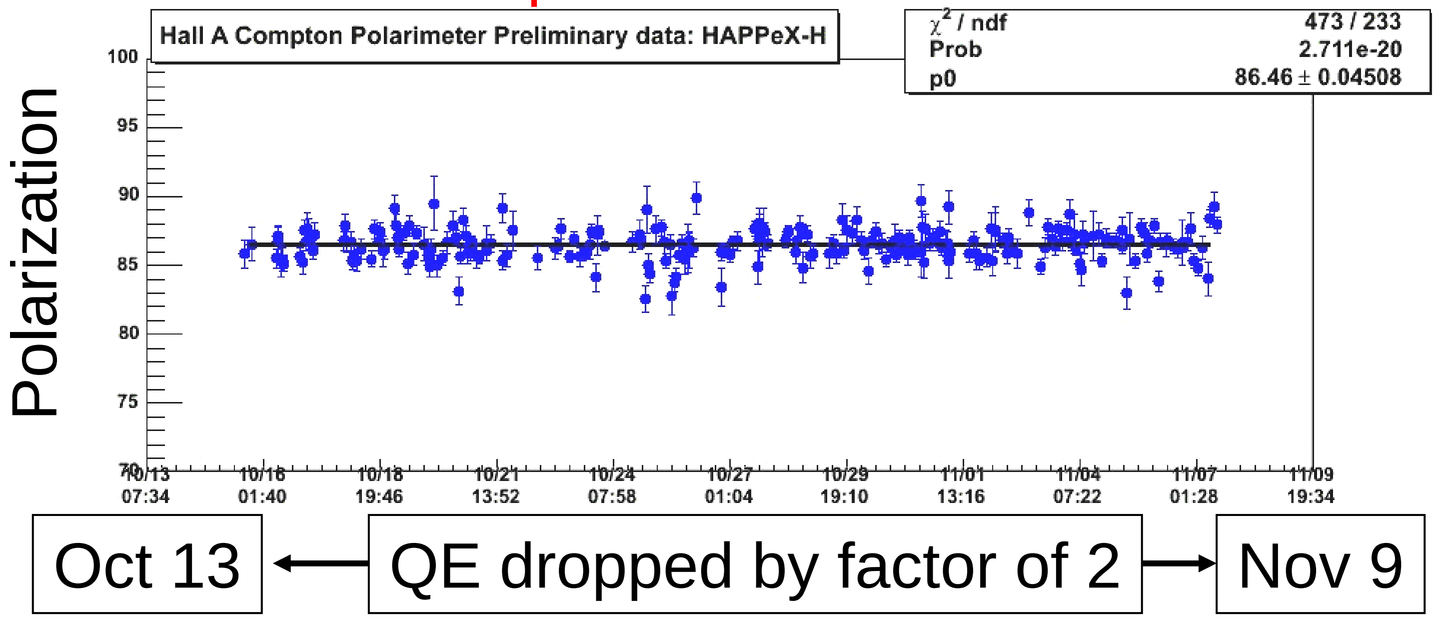
Anodized edge: a critical step. Eliminates electrons that hit beampipe walls





Superlattice Photocathodes

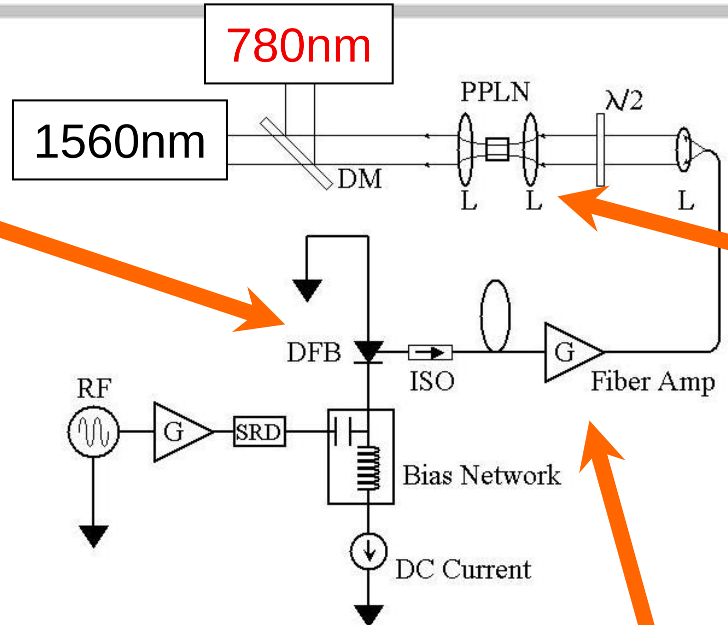
No depolarization over time!



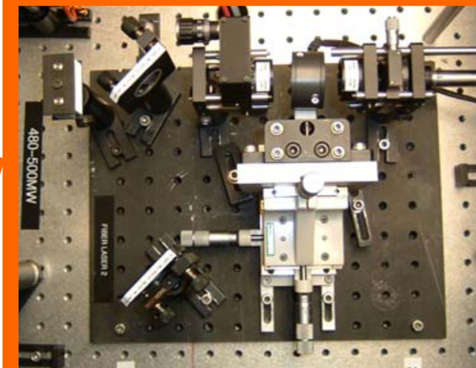
- One sample used from Sept 2005 through Apr 2007
- 7 activations, ~ 1000 C extracted, beam current to 200uA
- Max QE: 0.7 to 0.4%, Polarization ~ constant at 85%

Fiber-Based Drive Laser

Gain-switched seed

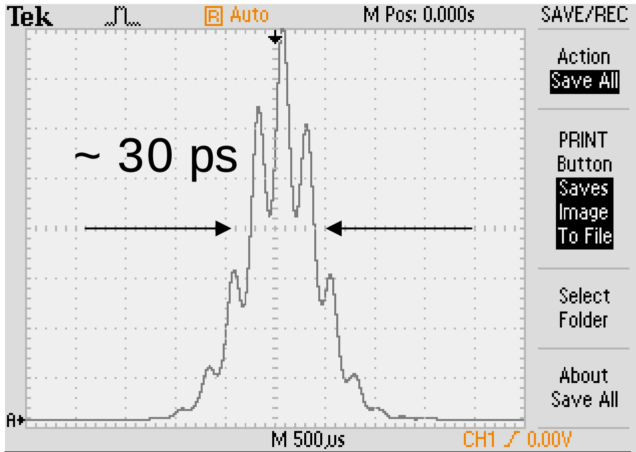


Frequency-doubler

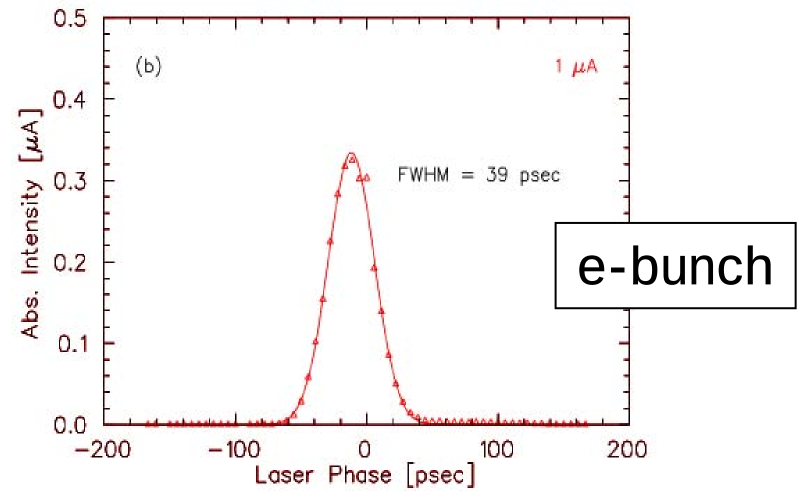


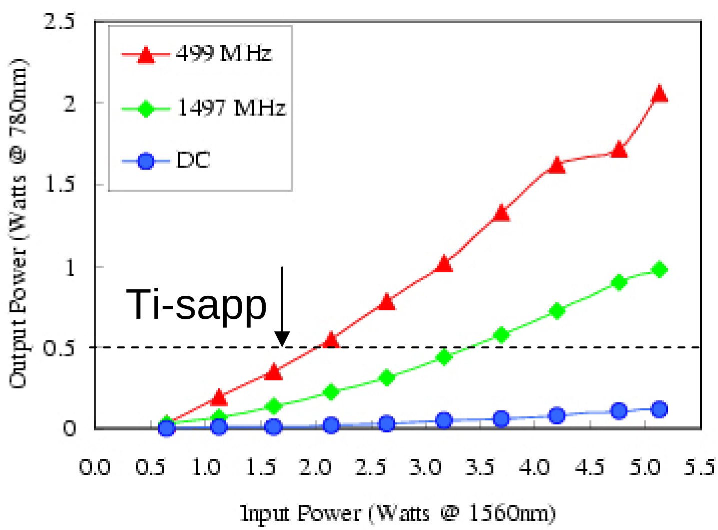
ErYb-doped fiber amplifier

Fiber-based Drive Laser



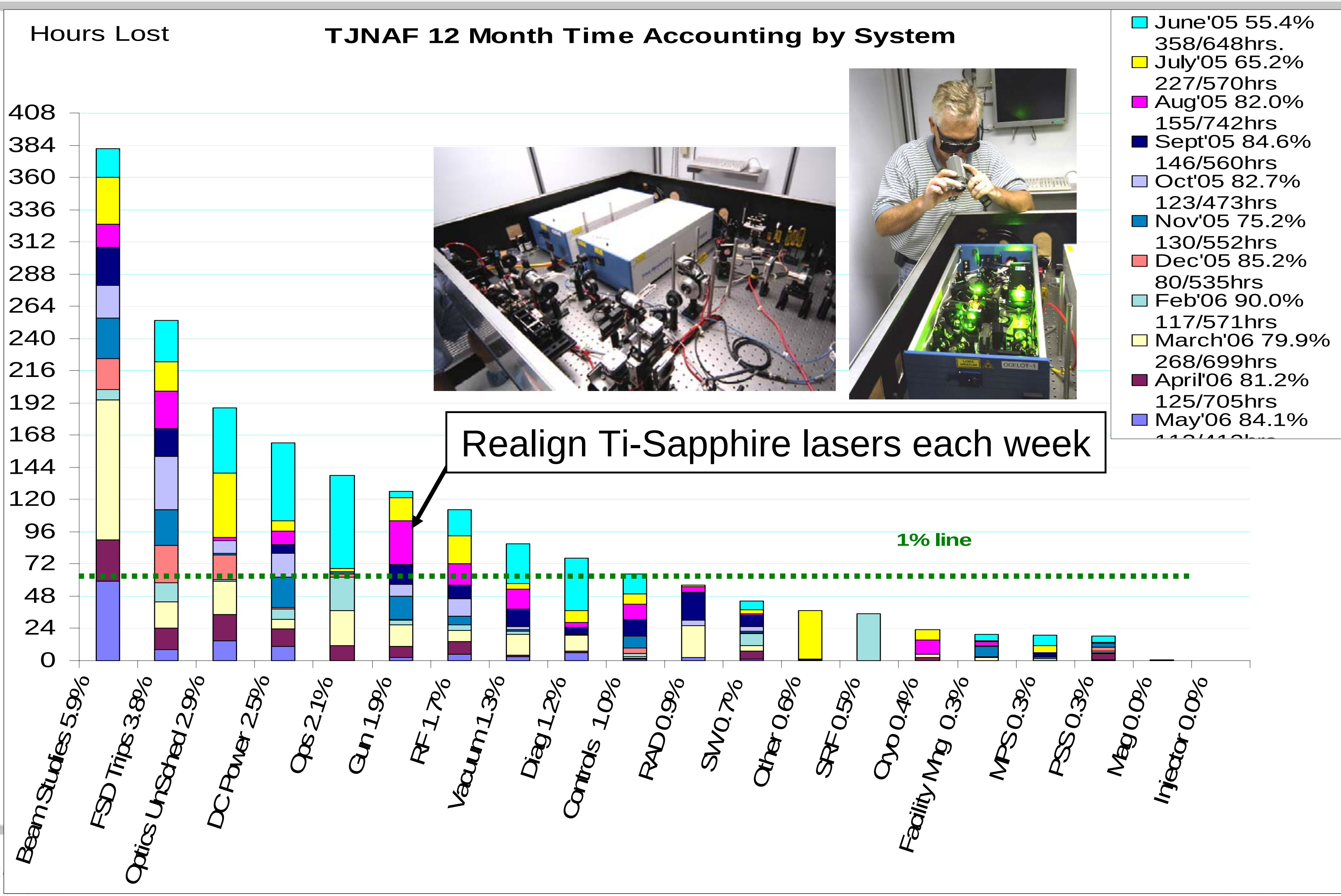
autocorrelator trace



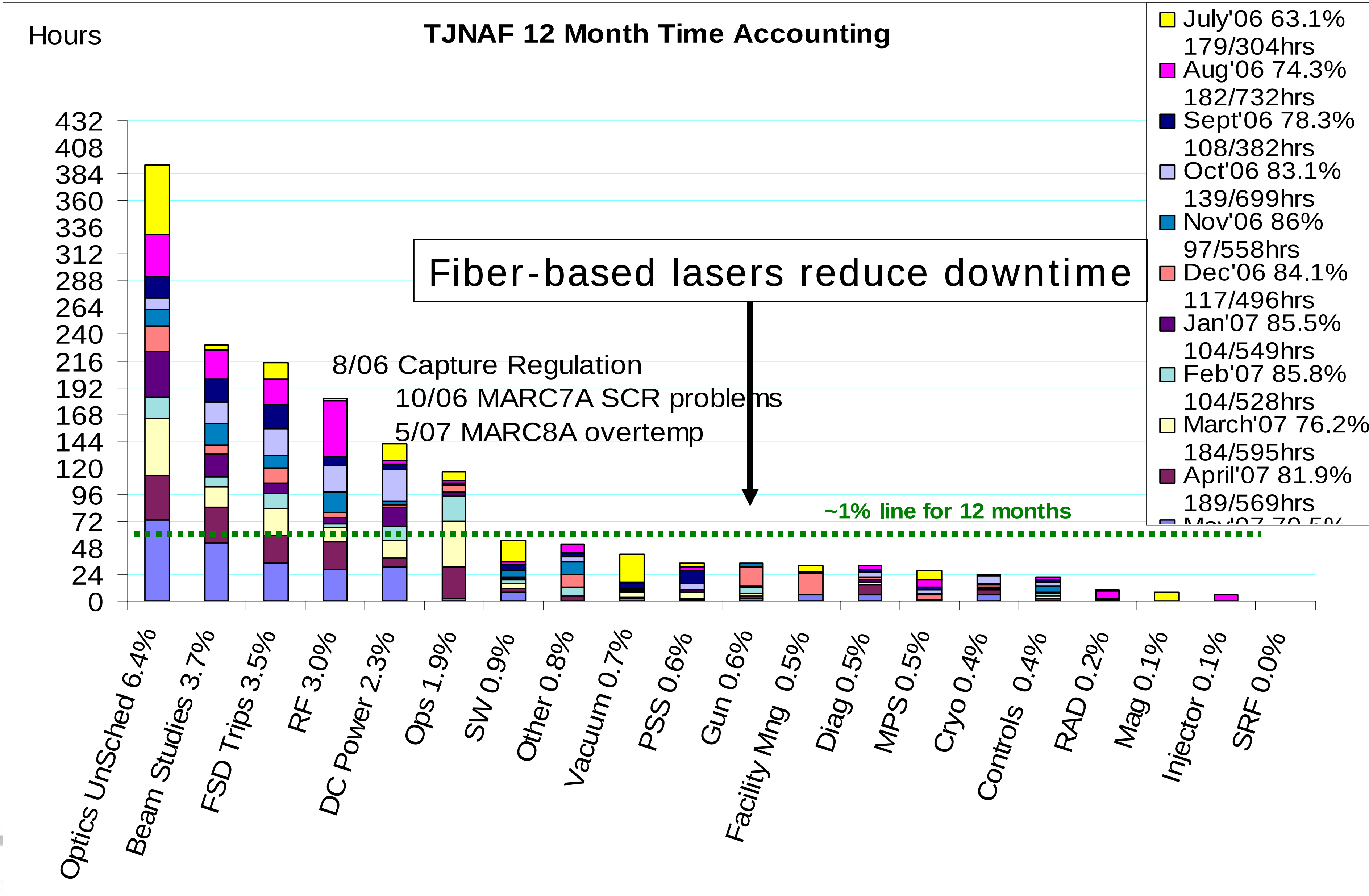


- CEBAF's last laser!
- Gain-switching better than modelocking; no phase lock problems, no feedback
- Very high power
- Telecom industry spurs growth, ensures availability
- Useful because of superlattice photocathode (requires 780nm)

Accelerator Downtime FY05Q4 – FY06Q3



Accelerator Downtime FY06Q4 – FY07Q3



Fiber-based Green Laser Development

IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 18, NO. 9, MAY 1, 2006 1013

High Average Power, High Repetition Rate, Picosecond Pulsed Fiber Master Oscillator Power Amplifier Source Seeded by a Gain-Switched Laser Diode at 1060 nm

P. Dupriez, A. Piper, A. Malinowski, J. K. Sahu, M. Ibsen, B. C. Thomsen, Y. Jeong, L. M. B. Hickey, M. N. Zervas, J. Nilsson, and D. J. Richardson

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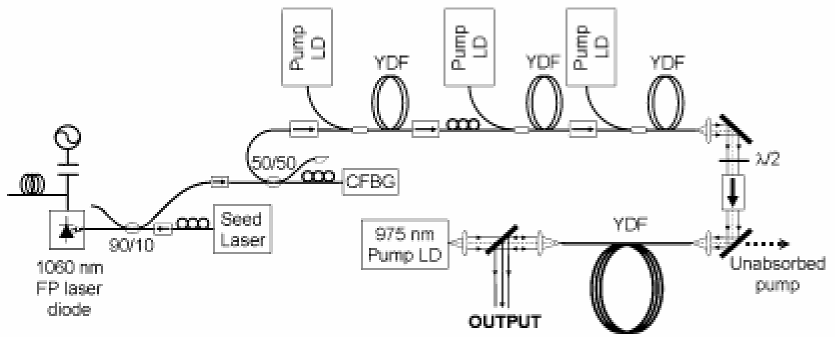
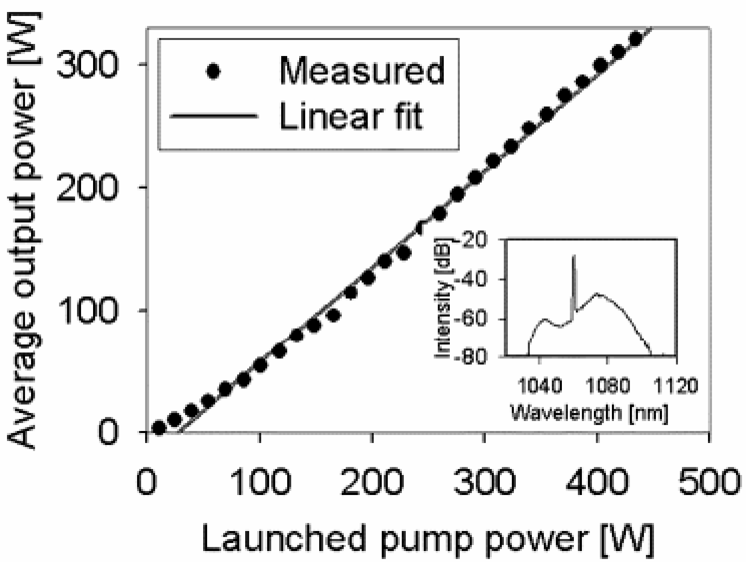


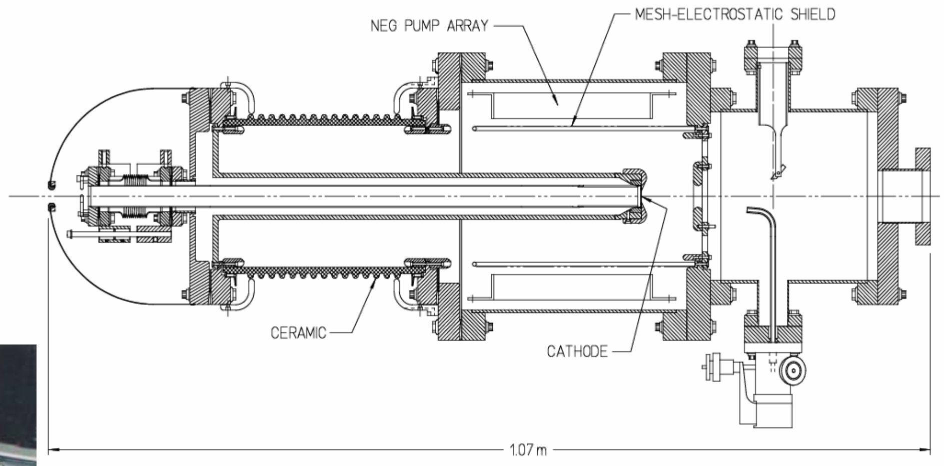
Fig. 1. Experimental setup. CFBG: chirped fiber Bragg grating. LD: laser diode.

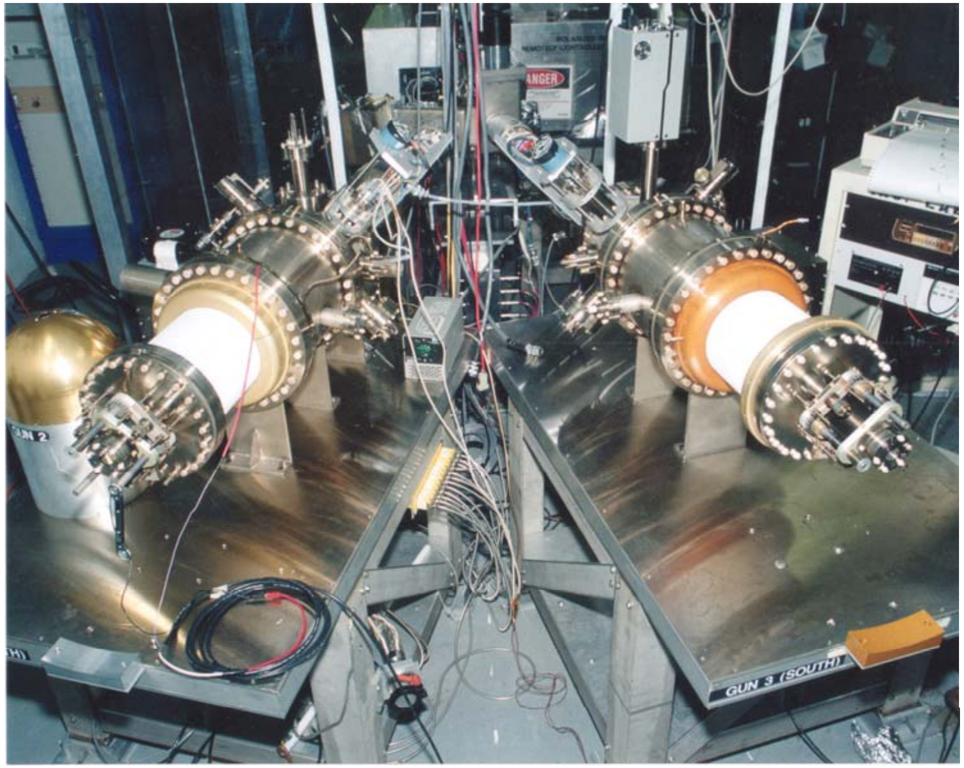
P. Dupriez, A. Malinowski, J. K. Sahu, M. Ibsen, Y. Jeong J. Nilsson, and D. J. Richardson are with the Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, U.K. (e-mail: pad@orc.soton.ac.uk).



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)

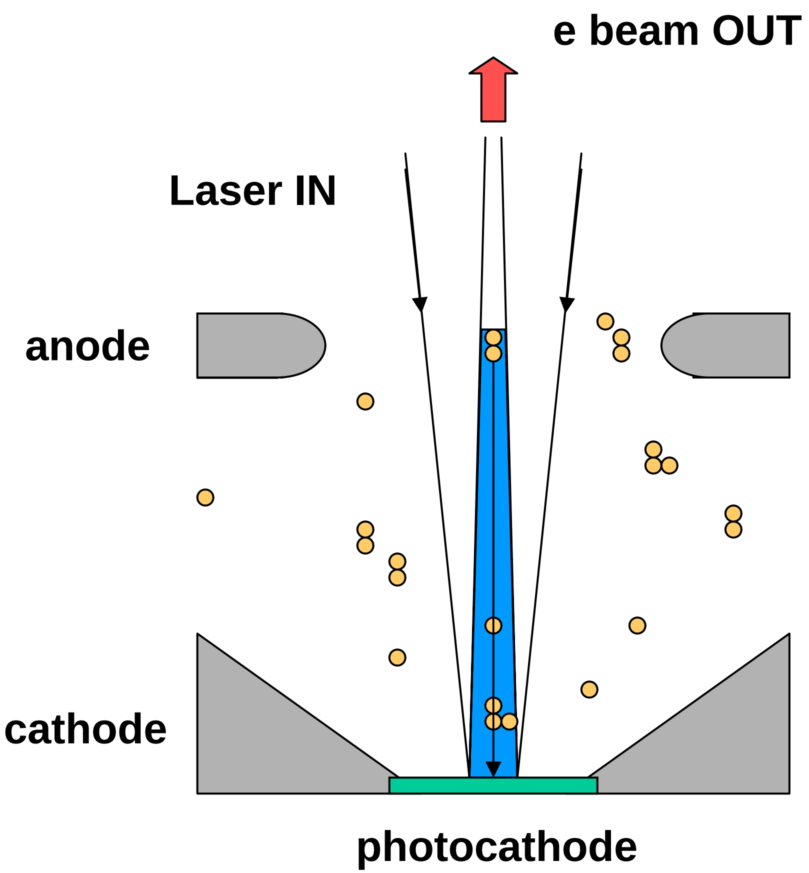


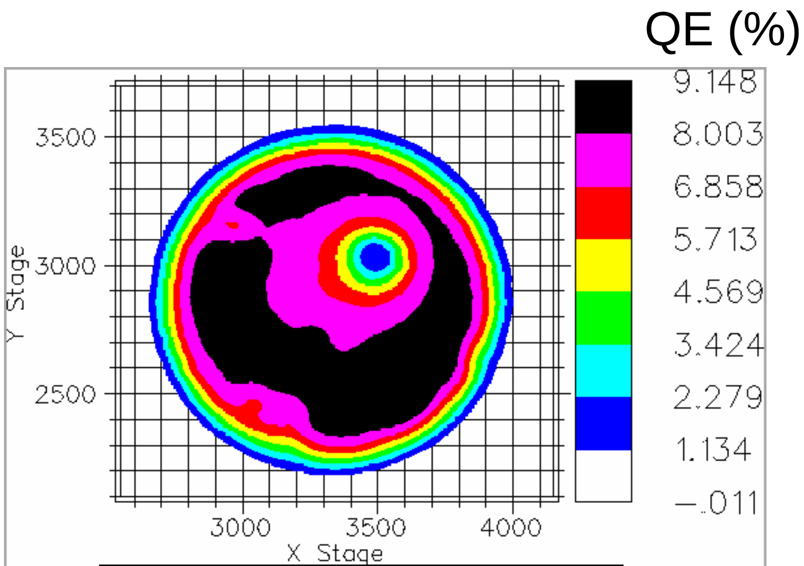


- Activate photocathode inside gun – no HV breakdown after 7 full activations (re-bake gun after 7th full activation)
- 13 mm photocathode, but use only center portion, 5 mm dia.
- Extract ~ 2000 Coulombs per year
- Beam current ~ 100uA, laser 0.5mm dia., lifetime: ~ 100C, 1×10^5 C/cm^2

What limits photogun lifetime?

Imperfect vacuum and Ion Backbombardment



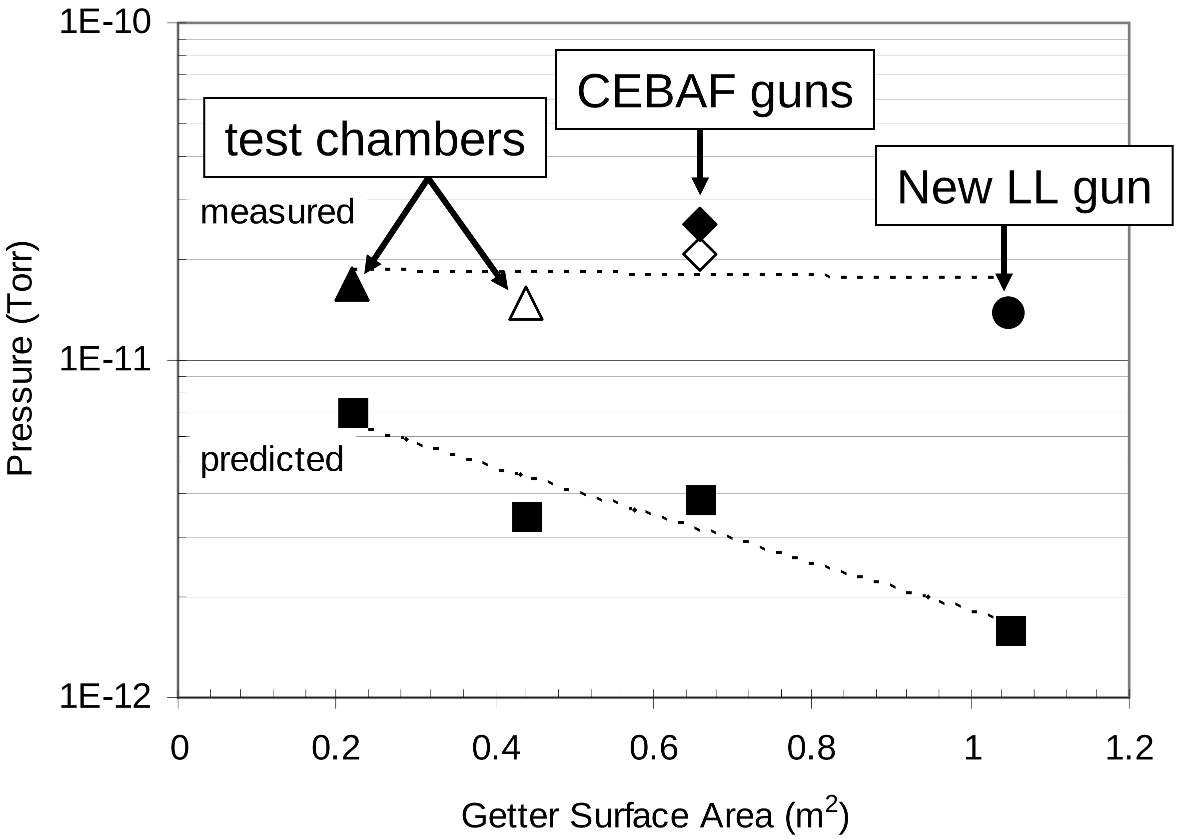


QE scan of photocathode

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

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

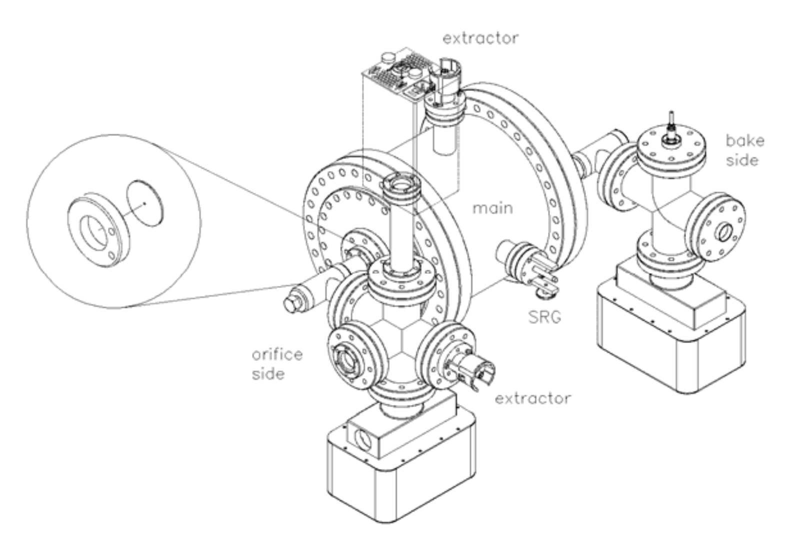


How to explain this discrepancy?

- Outgassing rate higher than assumed "standard" value; $1x10^{-12}$ Torr·L/s·cm^2?
- NEG pump speed smaller than SAES says?

Measured pressure always much greater than predicted

Outgassing Rate

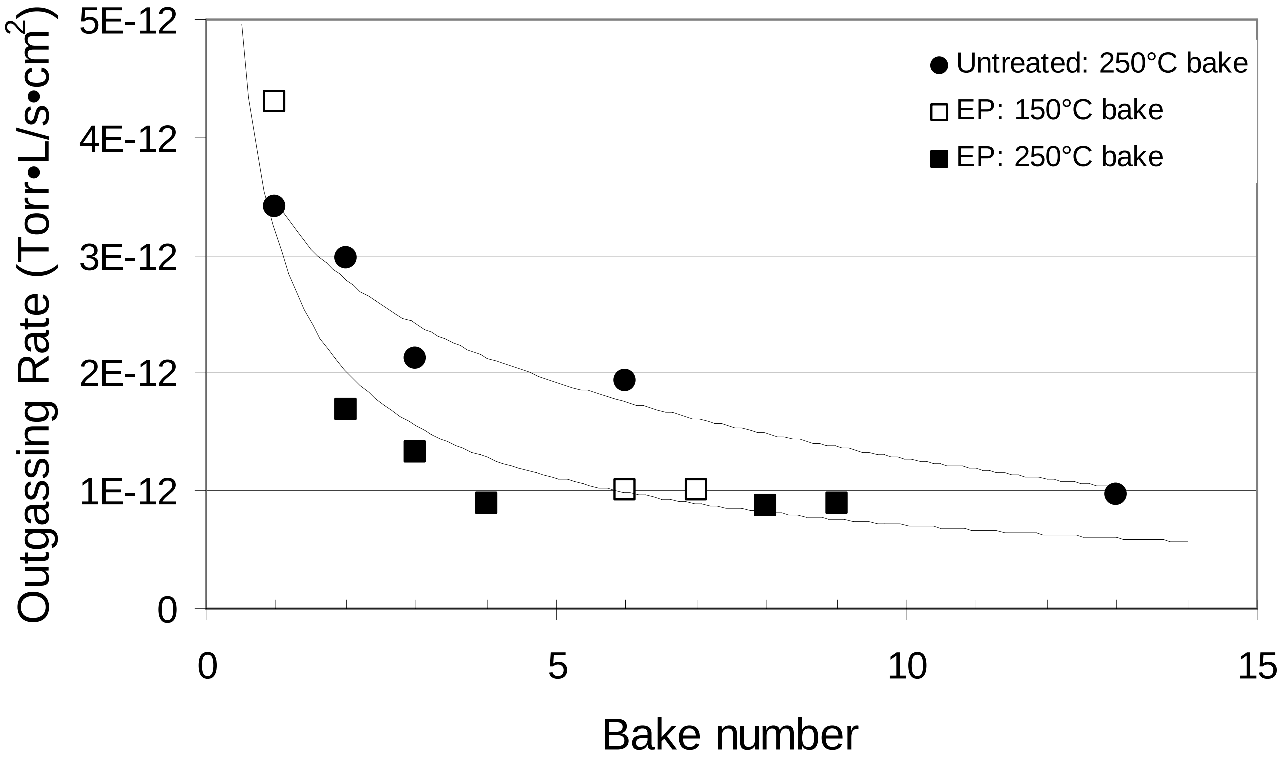


- Orifice and Rate of Rise Methods
- Studied 304, 316L and 6061 Al
- Degreasing and solvent cleaning vs EP and vacuum firing

	Preprocessing				In situ bake parameters		Outgassing Rate (Torr·L/s·cm^2)	
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}

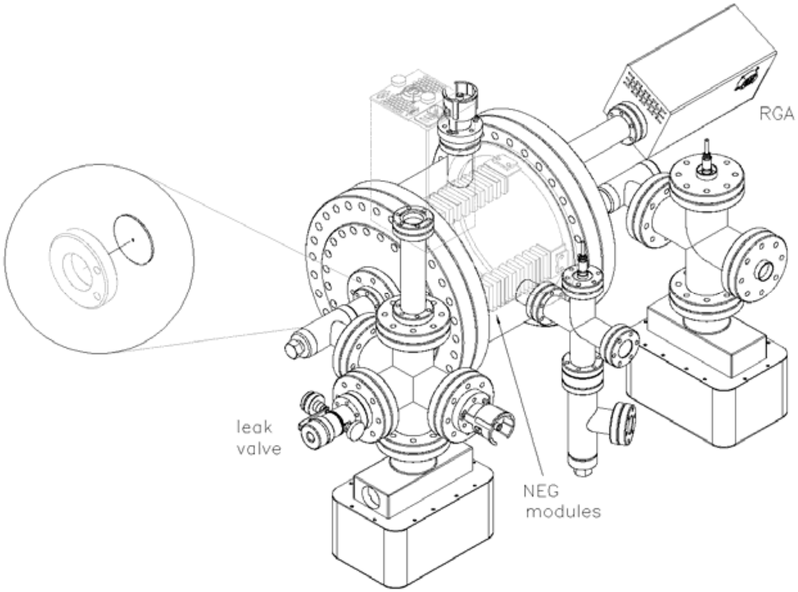
"Characterization of the CEBAF 100 kV DC GaAs Photoelectron Gun Vacuum System," M.L. Stutzman, et al., Nucl. Instrum. Meth. A, 574 (2007) p. 213-220

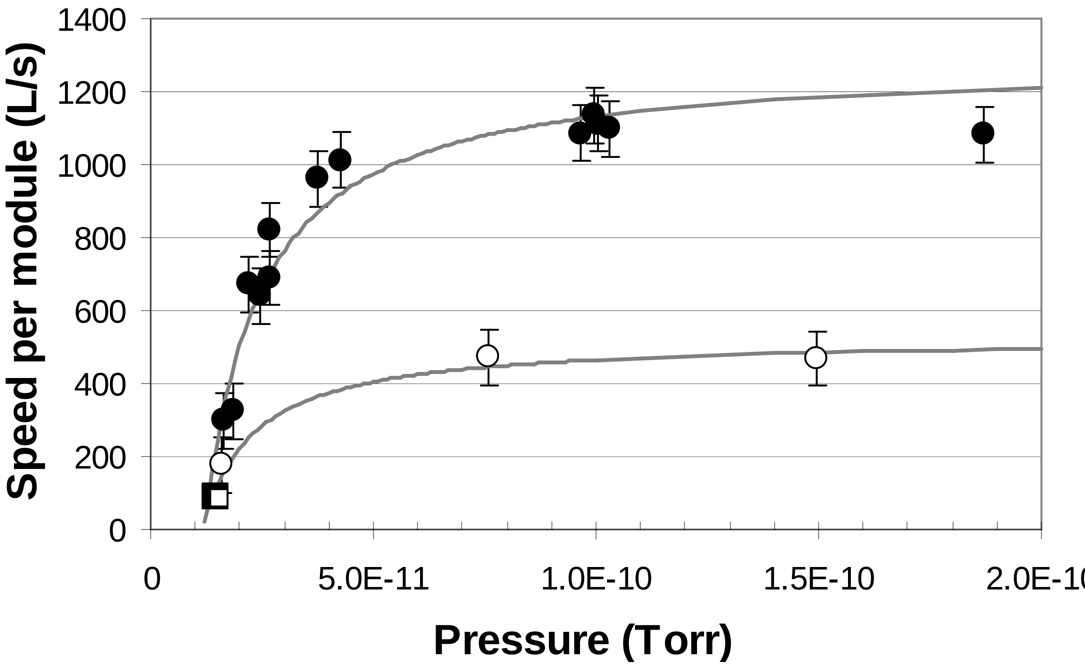
Benefit of EP and Vacuum Firing



- Electropolishing and vacuum firing provides low rate with fewer bakes
- The extremely low values (e.g., 10^{-15}) reported in literature elude us
- Conclusion: We have a “reasonable” outgassing rate ~ $1x10^{-12}$ Torr·L/s·cm^2

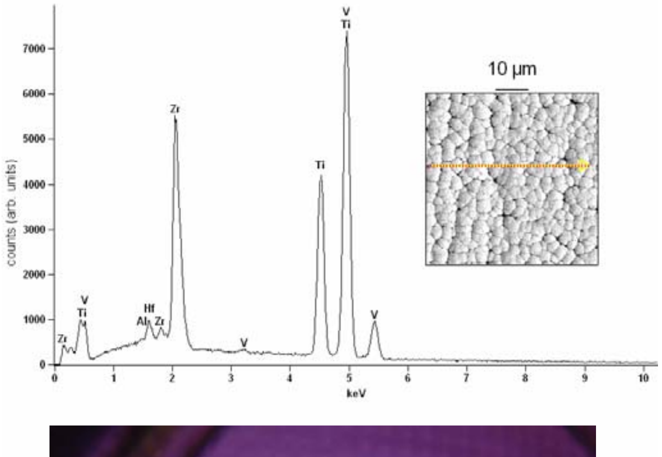
NEG Pump Speed

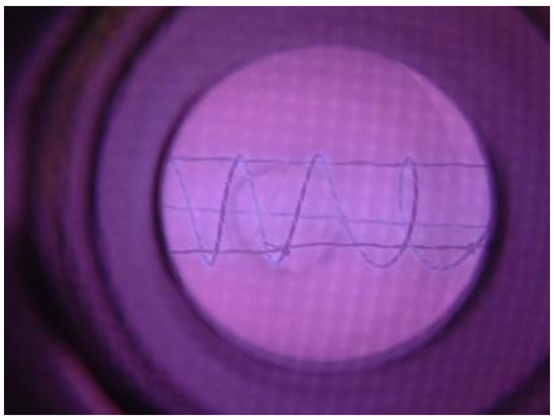


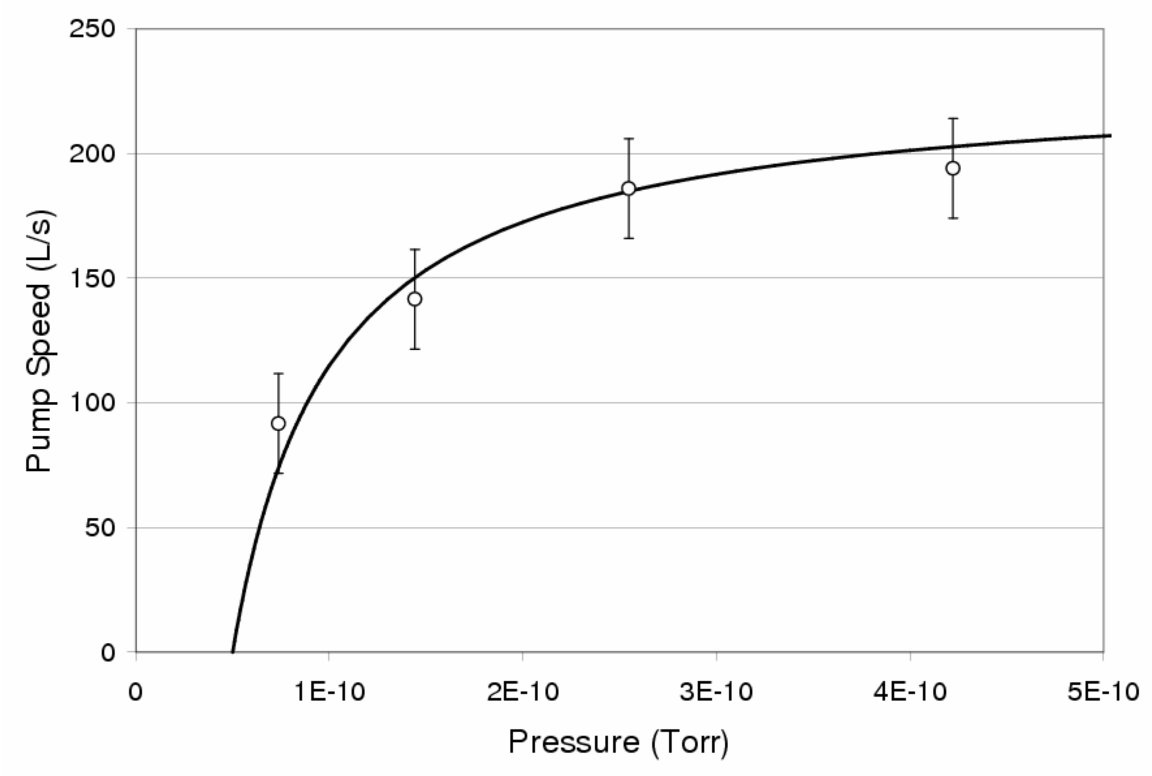


- Full NEG activation better than passive activation via bake
- NEG pump speed very good, at least at high pressure
- Conclusion: Can't explain reduced pump speed at low pressure – a real effect? More likely an indication of gauge limitations

NEG Coating

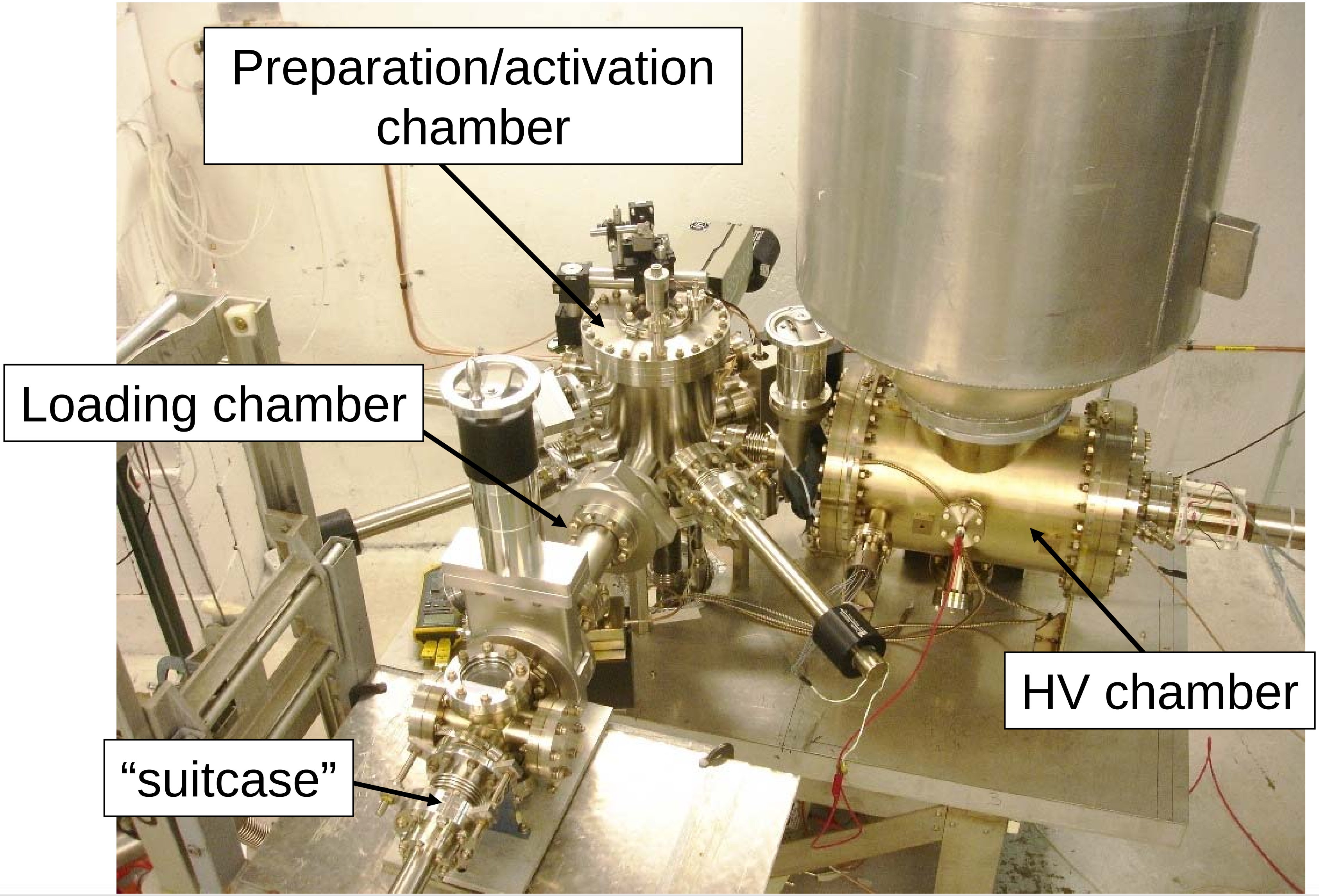






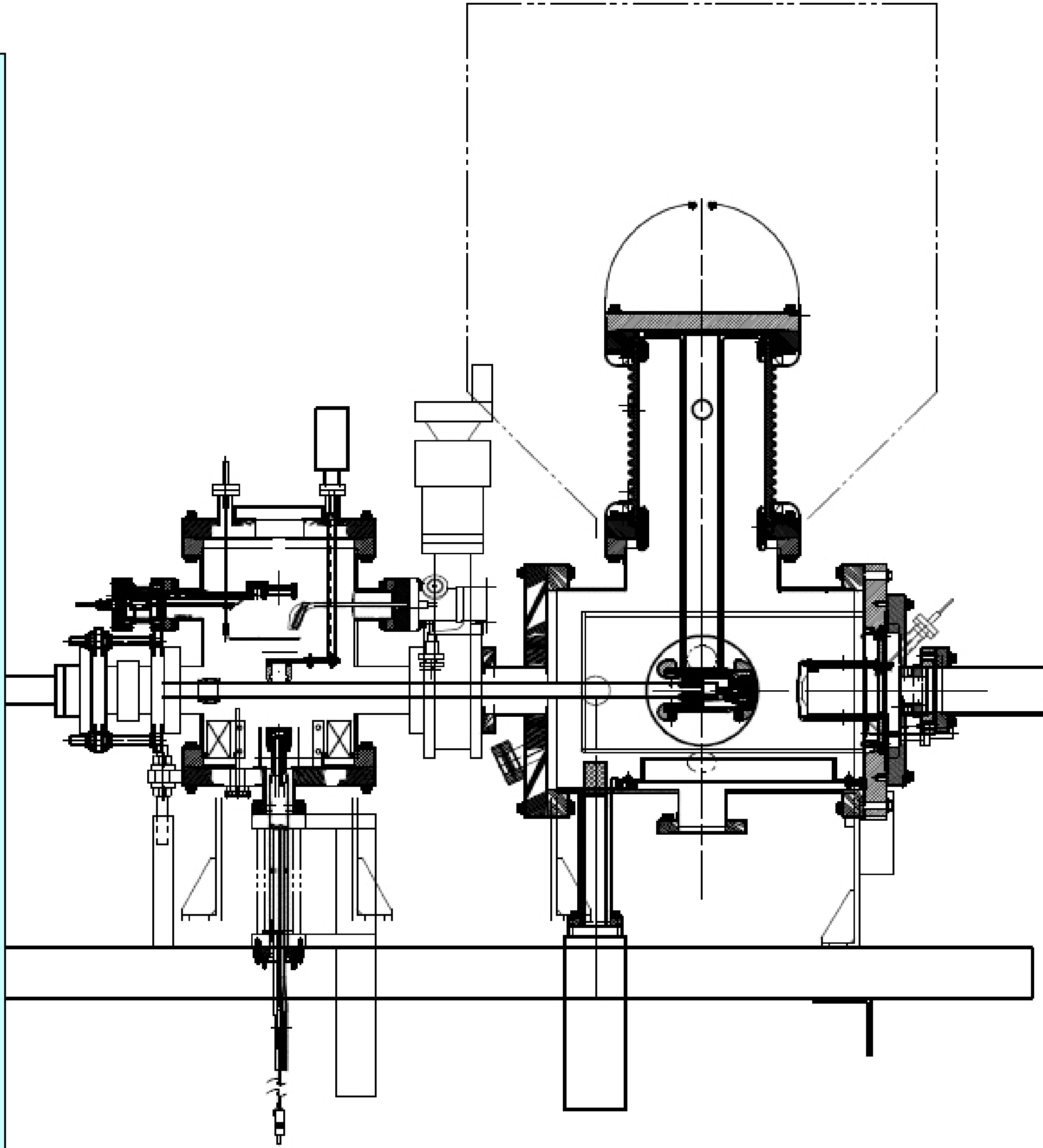
NEG coating turns a gas source into pump
~0.02 L/s·cm^2 : Modest pump speed can be improved

New CEBAF load-locked gun

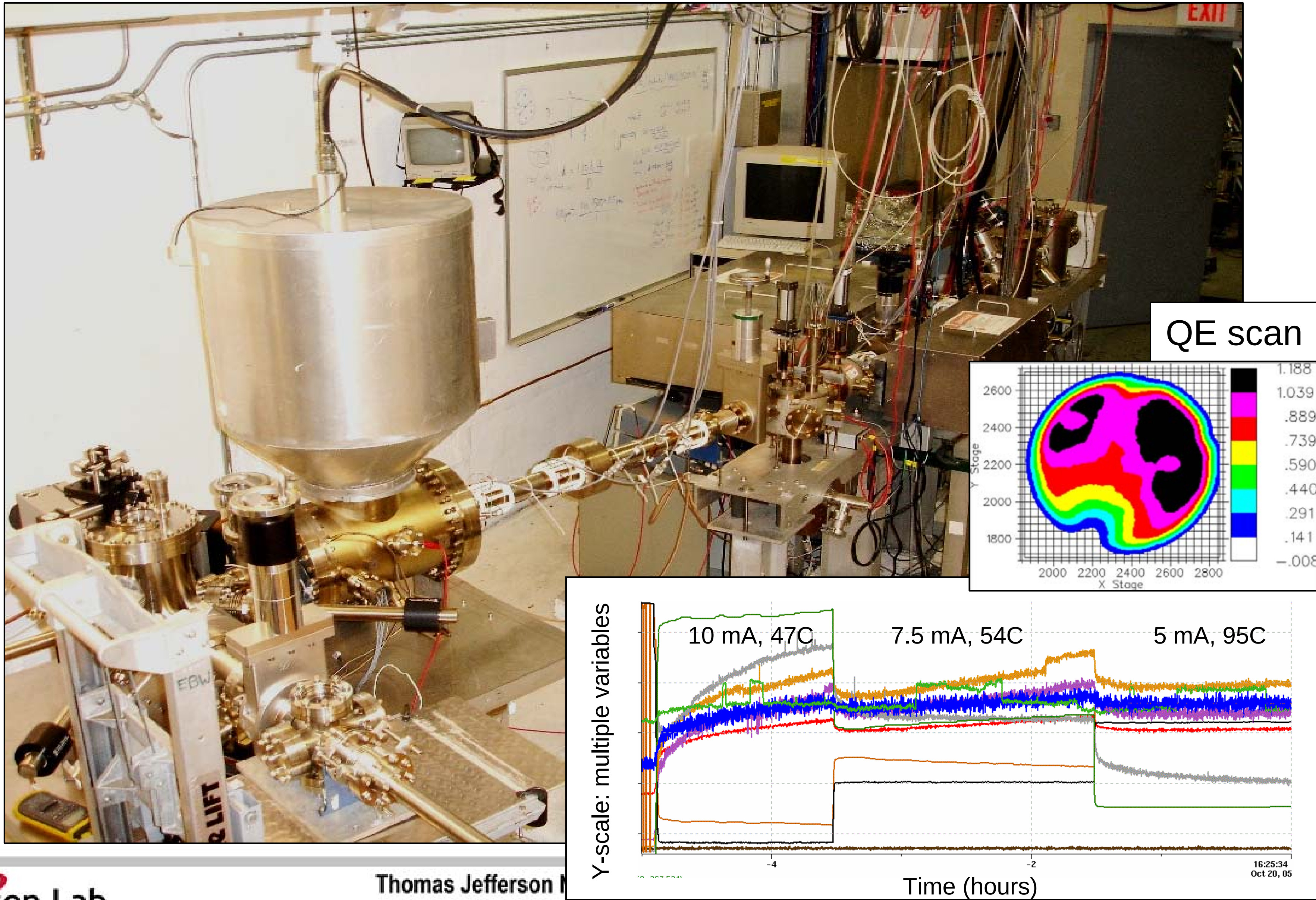


Key Features:

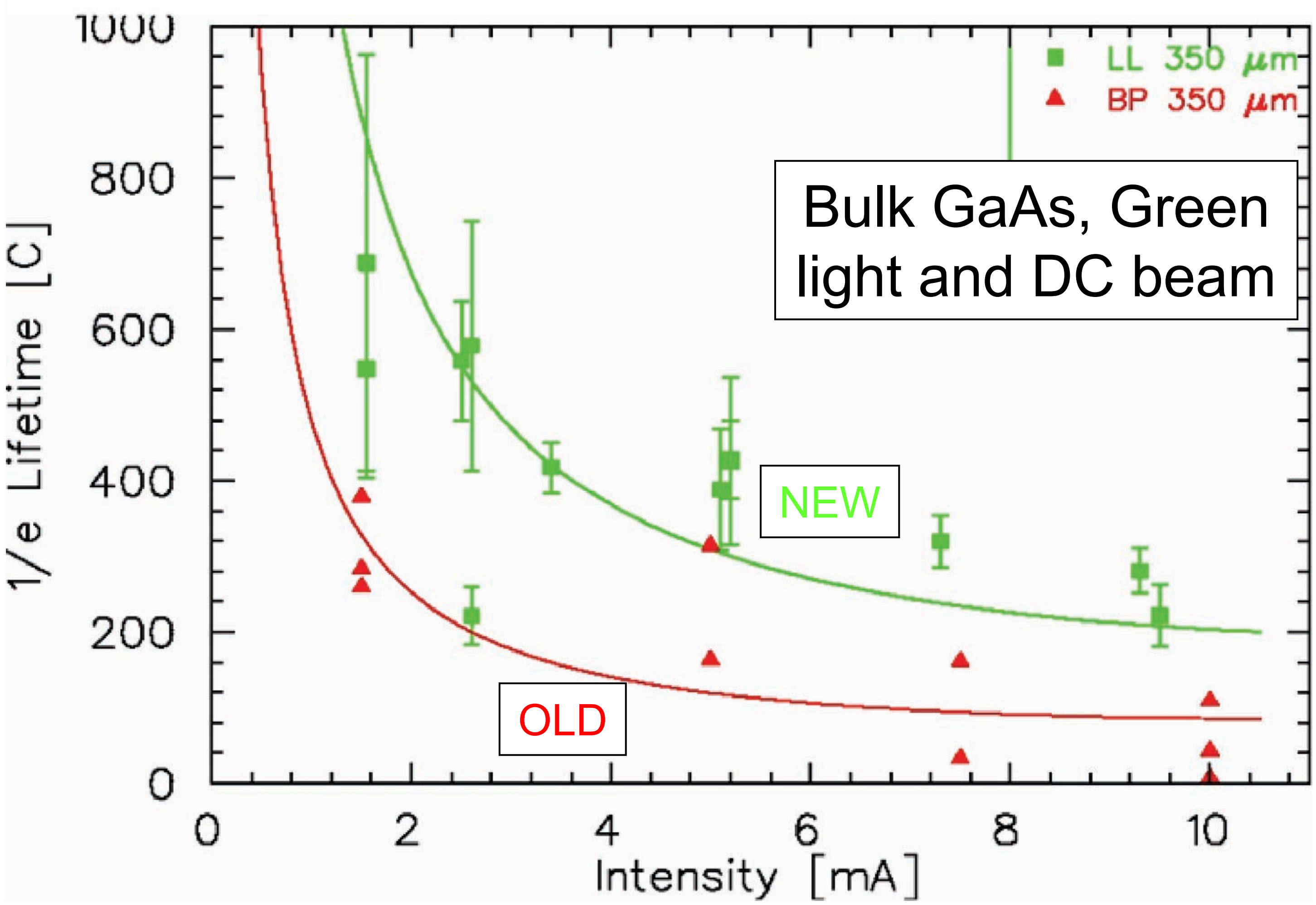
- Smaller surface area
- Electropolished and vacuum fired to limit outgassing
- NEG-coated
- Multiple pucks (8 hours to heat/activate new sample)
- Suitcase for installing new photocathodes (one day to replace all pucks)
- Mask to limit active area, no more anodizing



LL Gun and Test Beamline



Compare NEW and OLD load locked guns

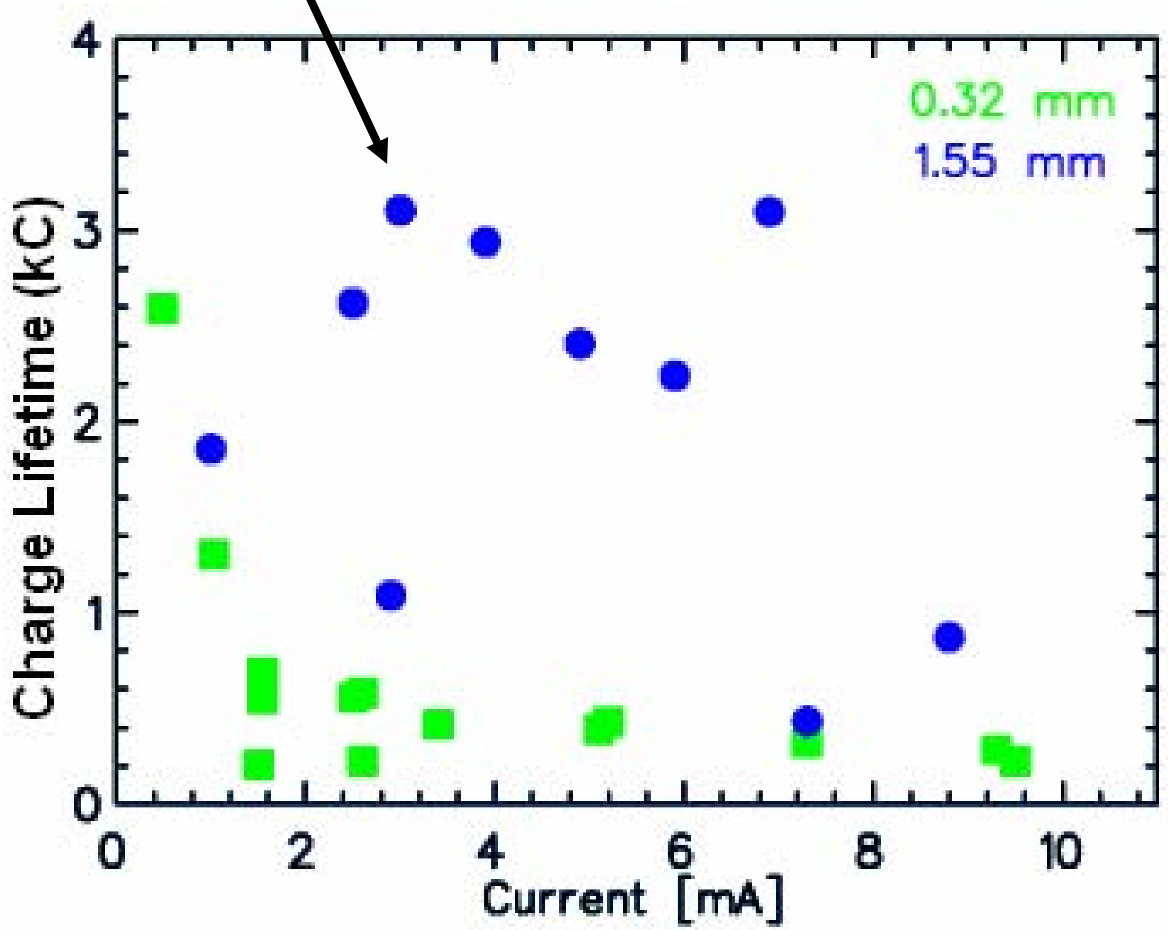


Photogun Lifetime - the best vacuum gauge

"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

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:

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

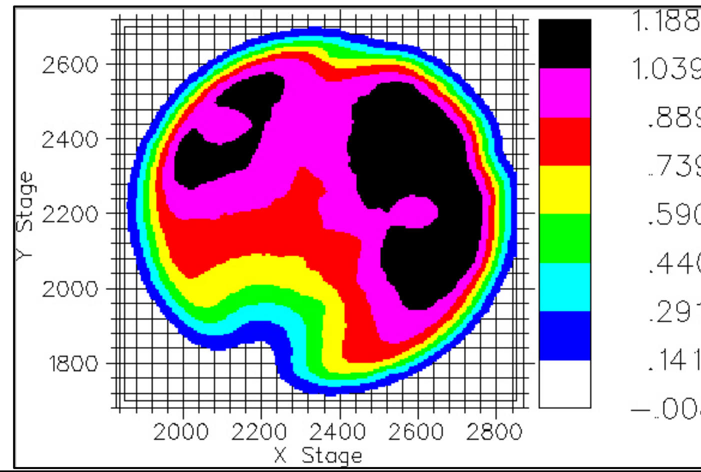
"Further Measurements of Photocathode Operational Lifetime at Beam Current > 1mA using an Improved 100 kV DC High Voltage GaAs Photogun," J. Grames, et al., Proceedings Polarized Electron Source Workshop, SPIN06, Tokyo, Japan

1mA at High Polarization*

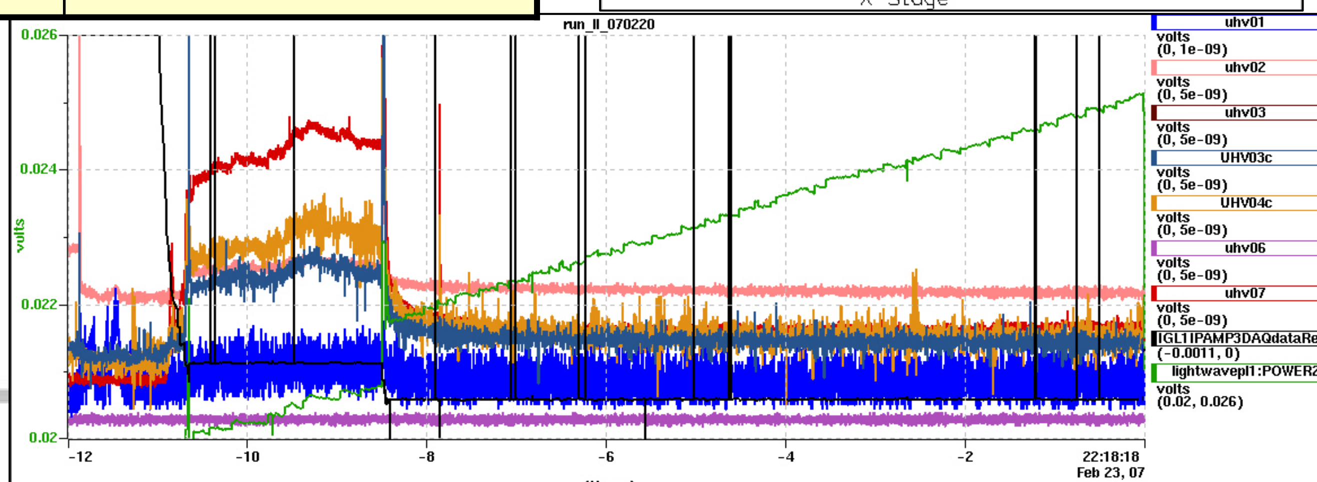
Parameter	Value
Laser Rep Rate	499 MHz
Laser Pulselength	30 ps
Wavelength	780 nm
Laser Spot Size	450 mm
Current	1 mA
Duration	8.25 hr
Charge	30.3 C
Lifetime	210 C
Charge Lifetime	160 kC/cm^2

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

High Initial QE



Vacuum signals
Laser Power
Beam Current



How Long Can We Run at 1mA?

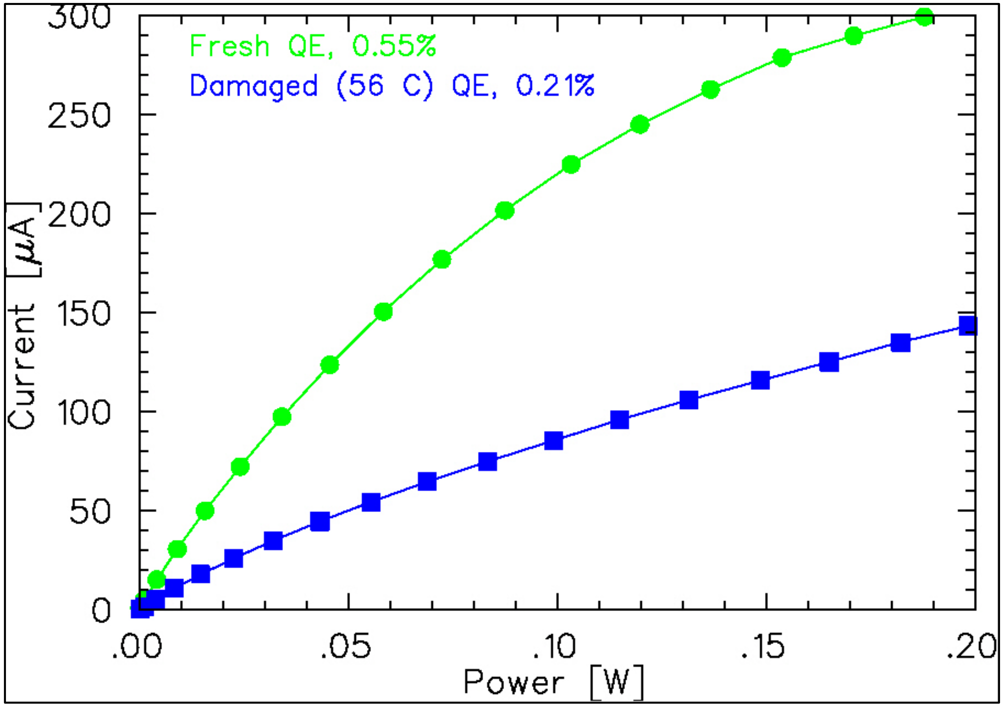
- 1mA operation, 3.6 C/hr, 86 C/day.
- Photocathode with 1% initial QE, 2W at 780nm and gun with 250C charge lifetime (Grames THPMS064)
- Initial laser power = 160mW to produce 1mA
- ***Should*** be able to operate at 1mA for 7 days before running out of laser power. Time to move to fresh photocathode 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

Conclusions: Future R&D

- More High Current Lifetime studies: biased anode (see Pozdeyev TUPMS079), increase gun voltage, reduce anode/cathode gap
- Cathode/anode design: managing ALL of the beam
- High Voltage: eliminating breakdown and field emission (high pressure rinse and coatings)
- Surface Charge Limit (QE not constant)
- How to measure UHV/XHV pressure? Modified Helmer gauge?
- Spintronics photocathodes, half-metals, high polarization and QE>>1%?
- Photocathode Cooling: needed when laser power exceeds ~ 1W