Polarized Electron Sources

Source Group Members –

Summer Students – Joan Dreiling, Maria Chevtsova, Matt Wood

JLab PhD Students - James McCarter, Ken Surles-Law

Junior Technicians – Josh Brittian, Jim Clark

Senior Technicians – Phil Adderley, John Hansknecht

Scientists – Matt Poelker, Marcy Stutzman, Riad Suleiman, Joe Grames

WebPage - www.jlab.org/accel/inj_group

Source Group Hall of Famers - Charlie Sinclair, Bruce Dunham, *Larry Cardman*, Scott Price, Peter Hartmann, Michael Steigerwald, Tony Day, *Kim Ryan*, *Danny Machie*, John Hogan, Bill Schneider, *Reza Kazimi*, Paul Rutt, *Ganapati Rao Myneni*

Detector Lecture
August 2, 2007

A history 30+ years and growing…

Polarized electron beams have wide application in studies which range from materials science to nuclear and high energy physics:

$\Rightarrow$ the latter has driven the development of polarized e- sources

Semiconductor sources introduced in 1975 via optical pumping of GaAs

First e- source on an accelerator (P ~ 35%) : PEGGY, at SLAC (1978)

Strained GaAs reaches higher polarization (P~75%) in early 90's (SLAC)

Strained Superlattice GaAs even higher (P~85%) last few years (SLAC)

Many accelerator facilities have had polarized e- GaAs sources:

CEBAF, MAMI, Bonn, *SLAC, MIT-BATES*

Unpolarized sources => electrons (10's, 100's mA) for Light Sources and now development for high current (10's mA) polarized beams.

Gallium Arsenide

3" wafer cleaved into square photocathodes (15.5 mm) for mounting on a "stalk" using In and Ta cup.

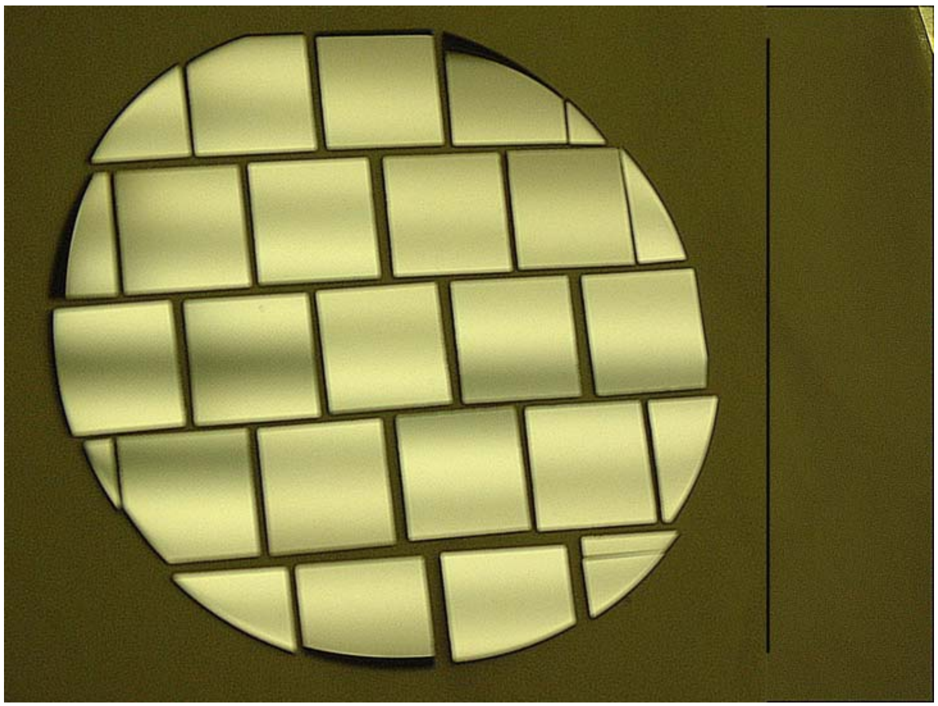
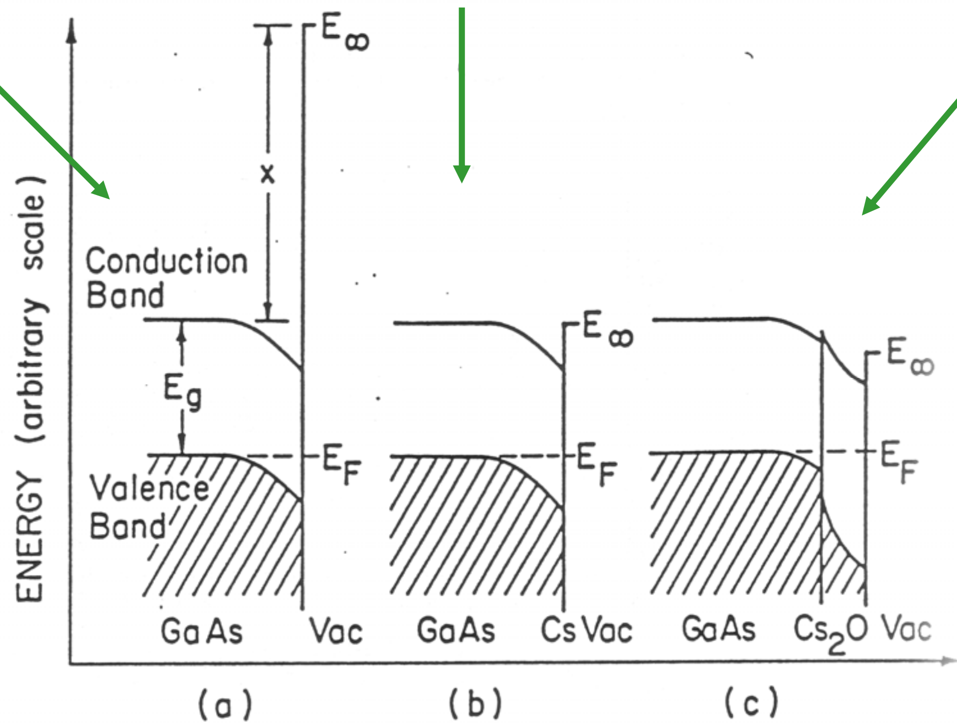


Photo-Emission from GaAs

Bare GaAs surface;
Large work function.
No electrons

Alkalai (Cs) reduces
work function.
Some electrons.

Cesium + Oxidant (O or NF3)
"Negative Electron Affinity".
Many electrons



$E_a > 0$ $E_a \approx 0$ $E_a < 0$

A Couple Things You'll Hear Me Say…

QE = Quantum Efficiency

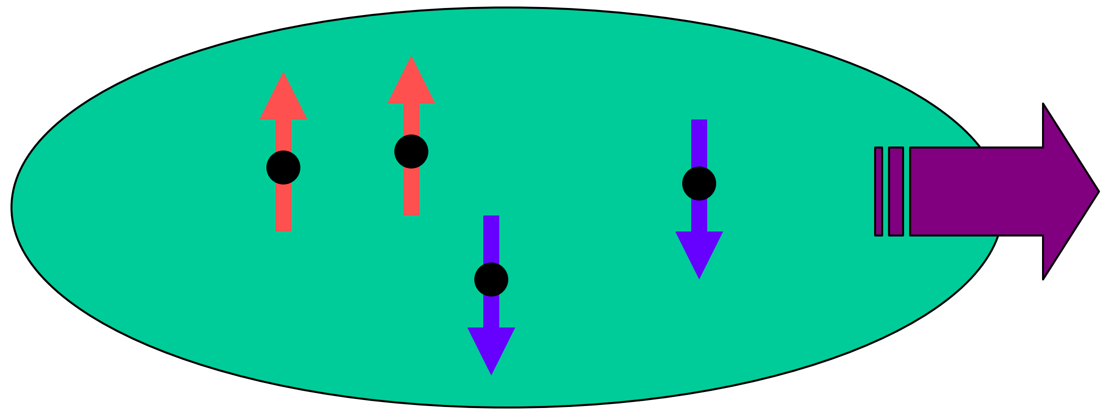
- # electrons out for # photons in
- 124 I[μA] / (P[mW] * λ[nm])
- 1% QE @ 780 nm => 6.3 μA/mW

1/e QE = QE Death !!!

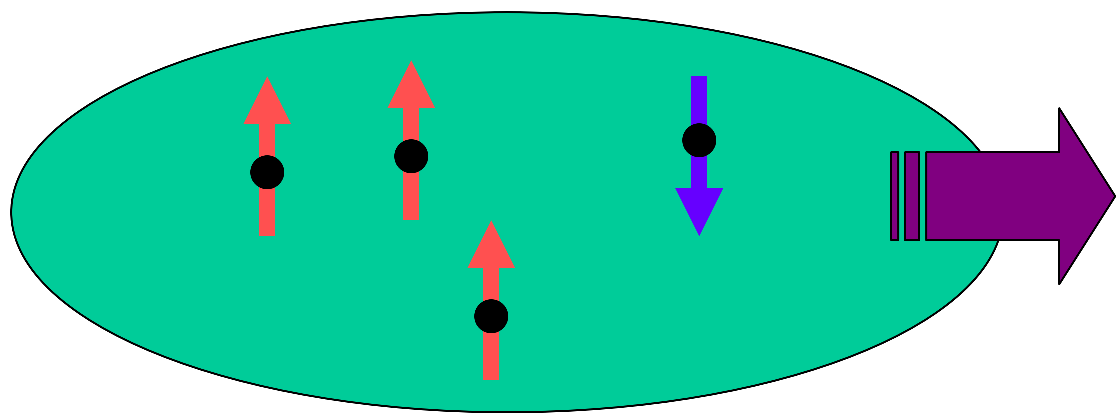
- Gauges how much QE reduces
- 1/e ~ 37% (1/3rd) of initial value

Electron Spin & Polarization

0% Polarization
☹

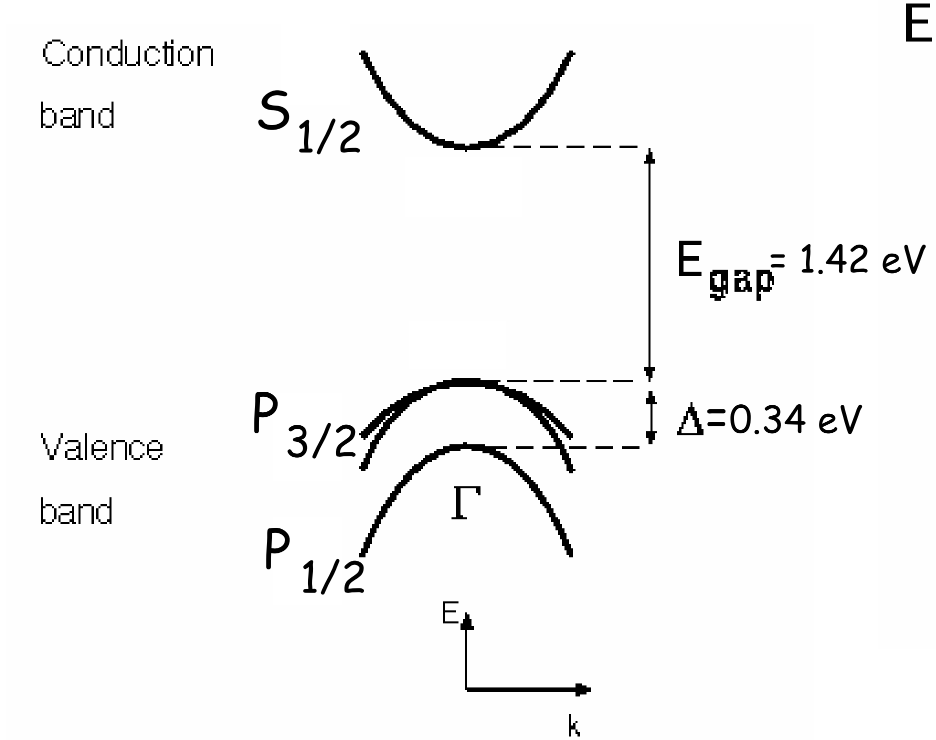


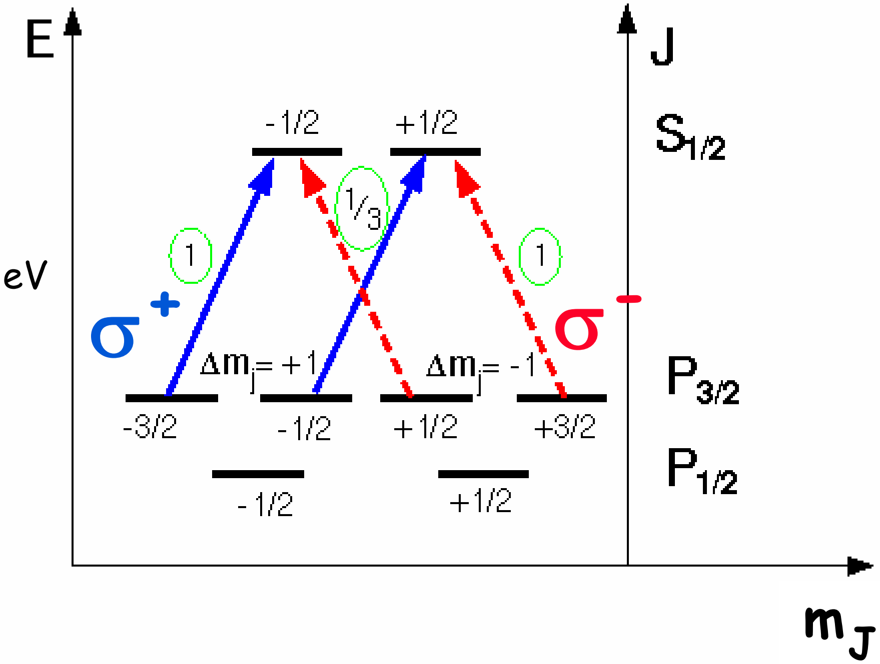
50% Polarization
☺



Aligning the Spin States in GaAs

Optical pumping between $P_{3/2}$ and $S_{1/2}$





$$E_{gap} < E_{\gamma} < E_{gap+\Delta}$$

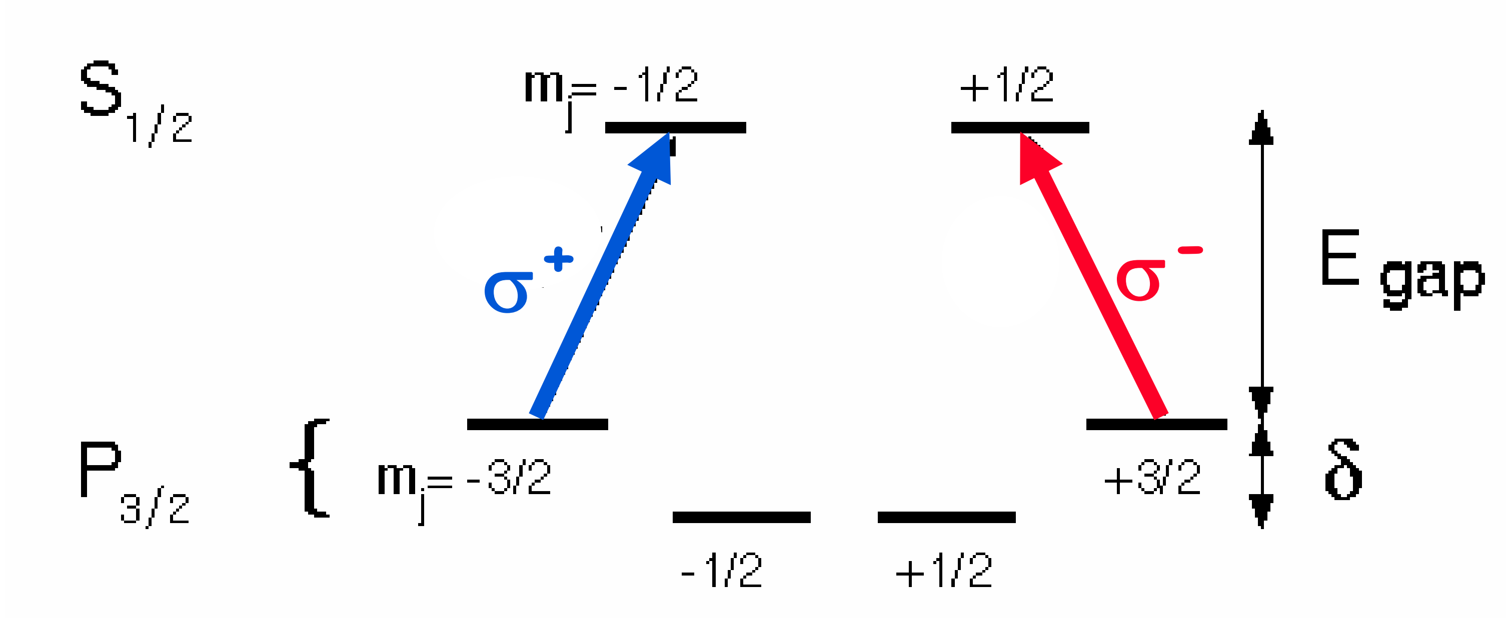
hc / λ

$$P_e = \frac{3-1}{3+1} = +/- \ 50\%$$

More would be nicer …

Split degeneracy of $P_{3/2}$

& optical pumping between $P_{3/2}$ and $S_{1/2}$



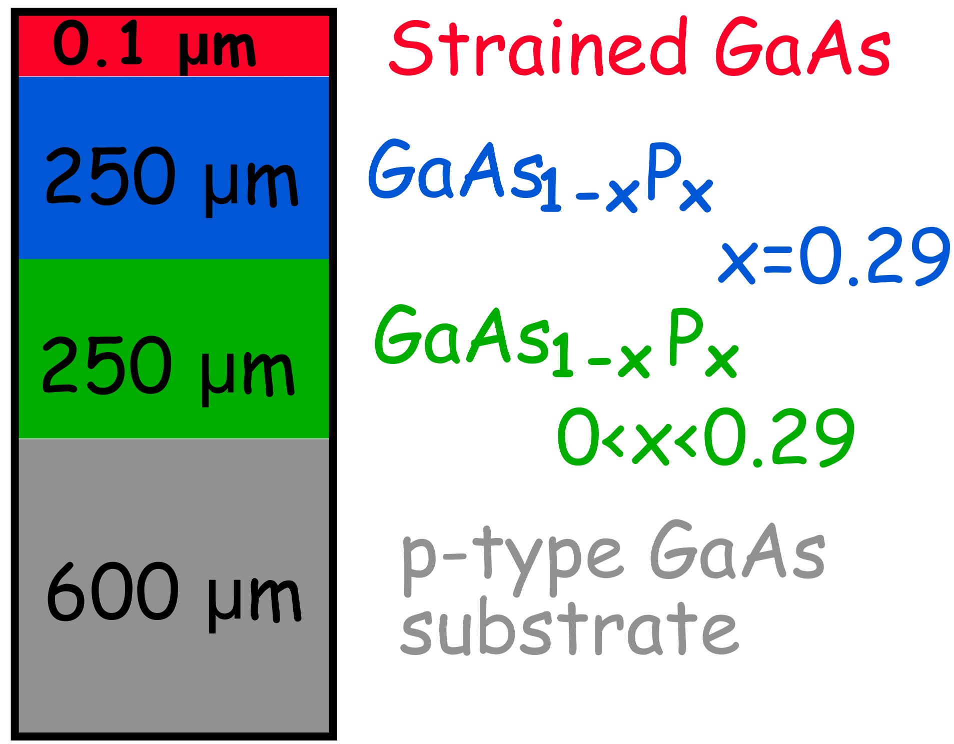
$$P_e = +/-\ 100\%, \text{ with } E_{gap} < E_\gamma < E_{gap+\delta}$$

Strained layer GaAs

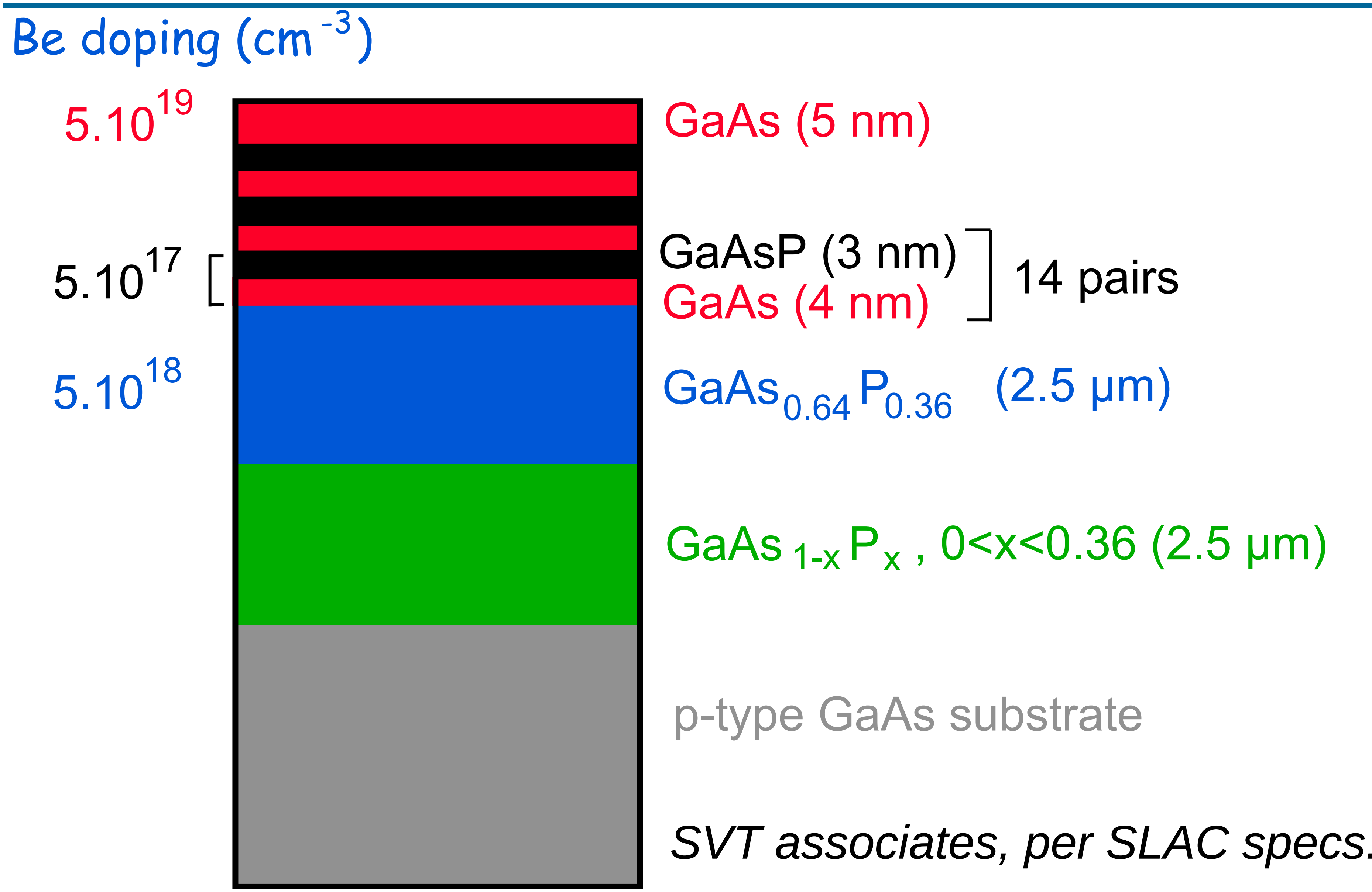
Bandwidth Semiconductor (formerly *SPIRE*)

- MOCVD-grown epitaxial spin-polarizer wafer
- Lattice mismatch

$\Rightarrow$ split degeneracy of $P_{3/2}$



Strained Layer - Superlattice GaAs

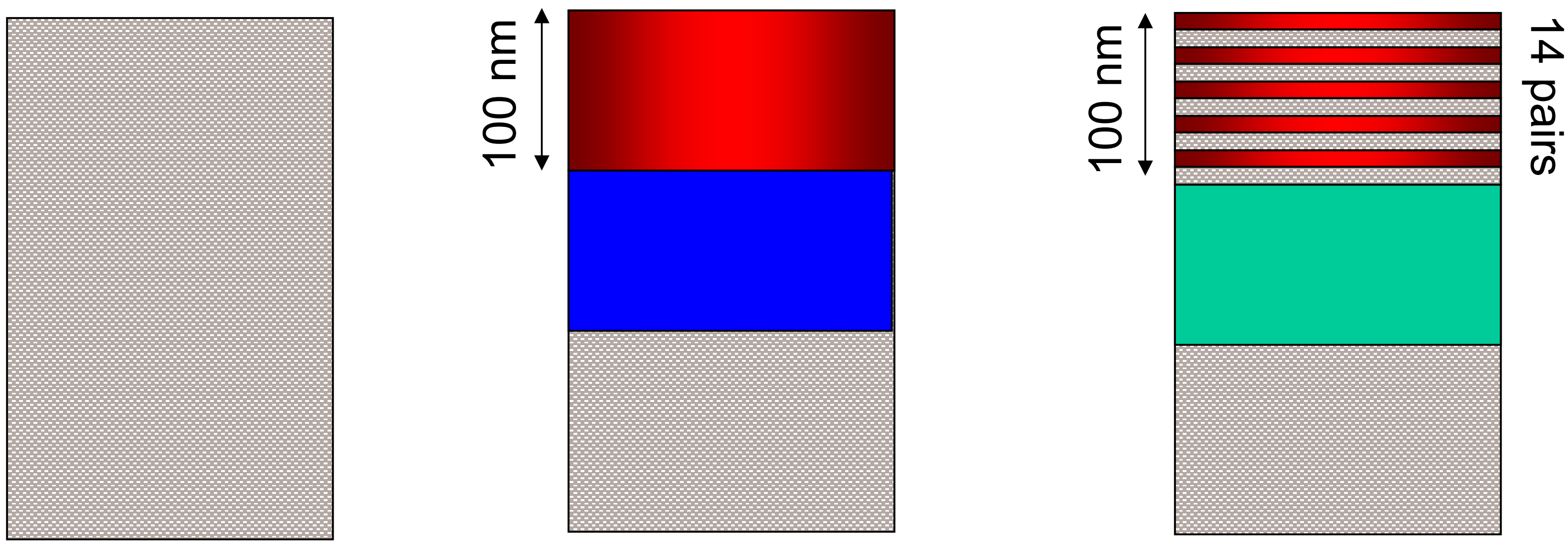


Photocathode Material

Bulk GaAs

Strained GaAs:
GaAs on GaAsP

Superlattice GaAs:
Layers of GaAs on GaAsP



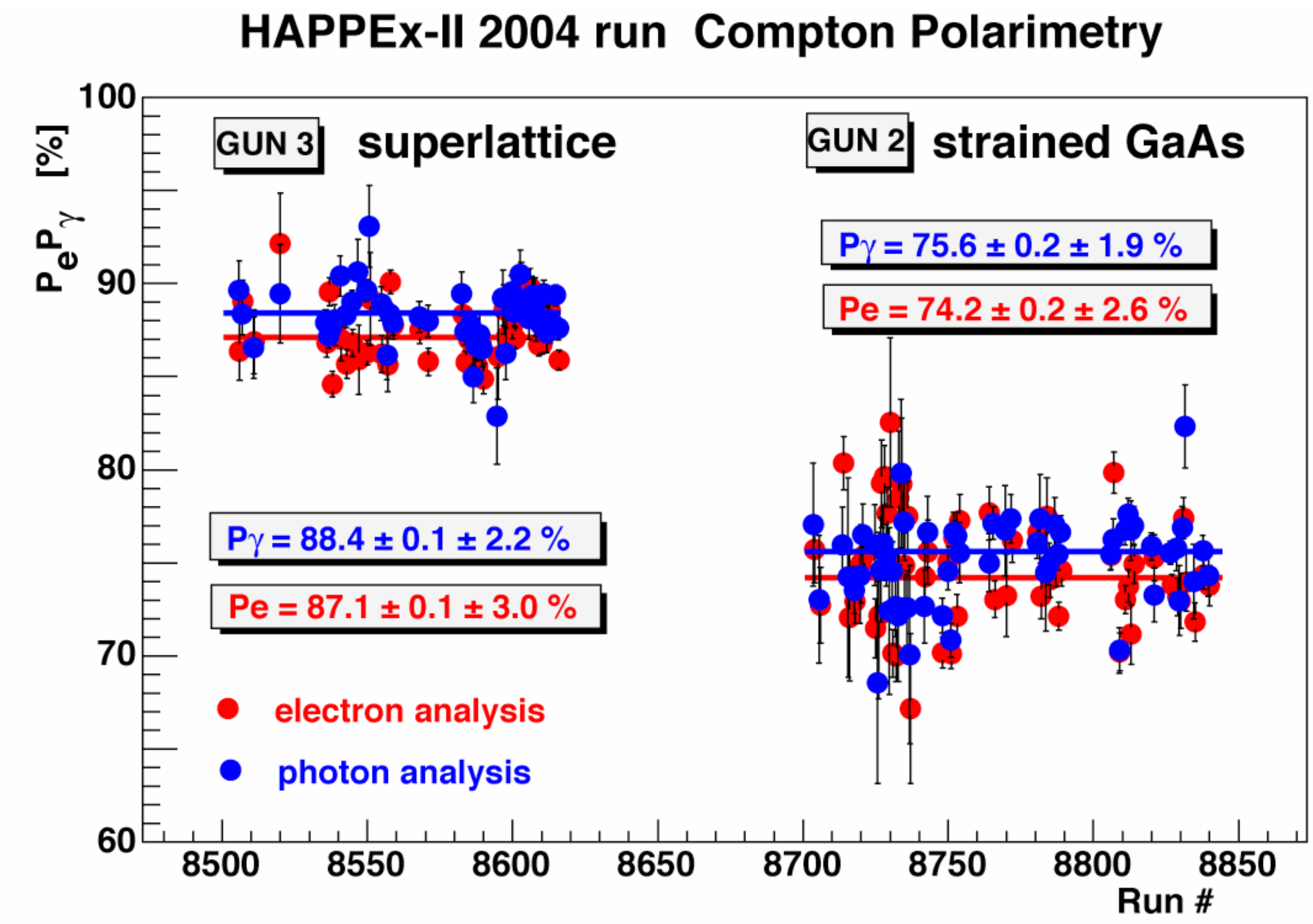
High QE ~ 8%
Pol ~ 35%

"conventional" material
QE ~ 0.2%
Pol ~ 75%
@ 850 nm

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

$$\mathbf{FOM} \propto I\,P^2$$

And, it really works!



Experiment Figure of Merit

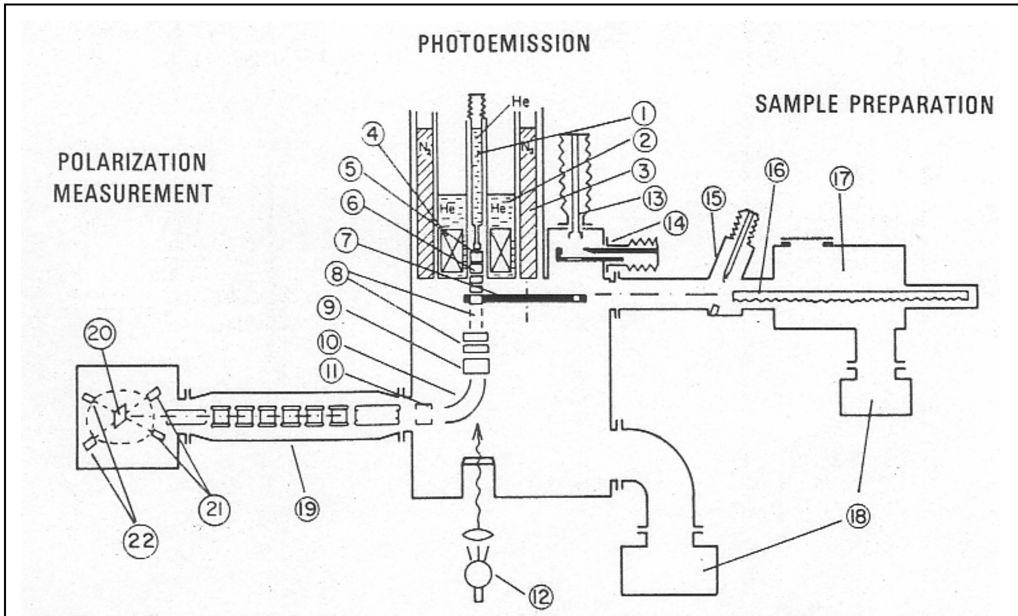
$$\frac{P_{sup.}^2 I}{P_{str.}^2 I} = 1.38$$

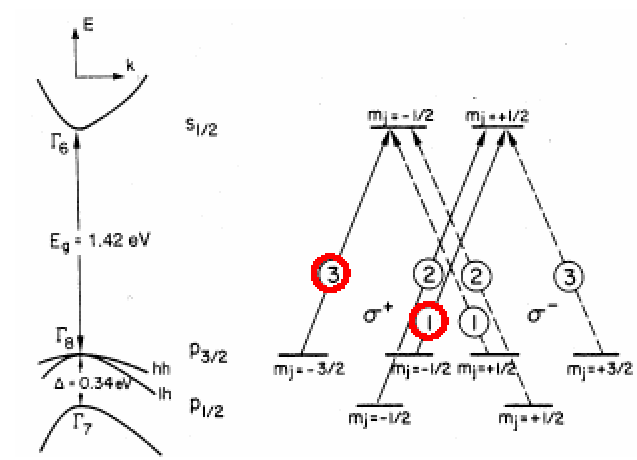
The First GaAs Photoemission Gun

PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier
Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH 8049, Zürich, Switzerland
(Received 10 February 1976)





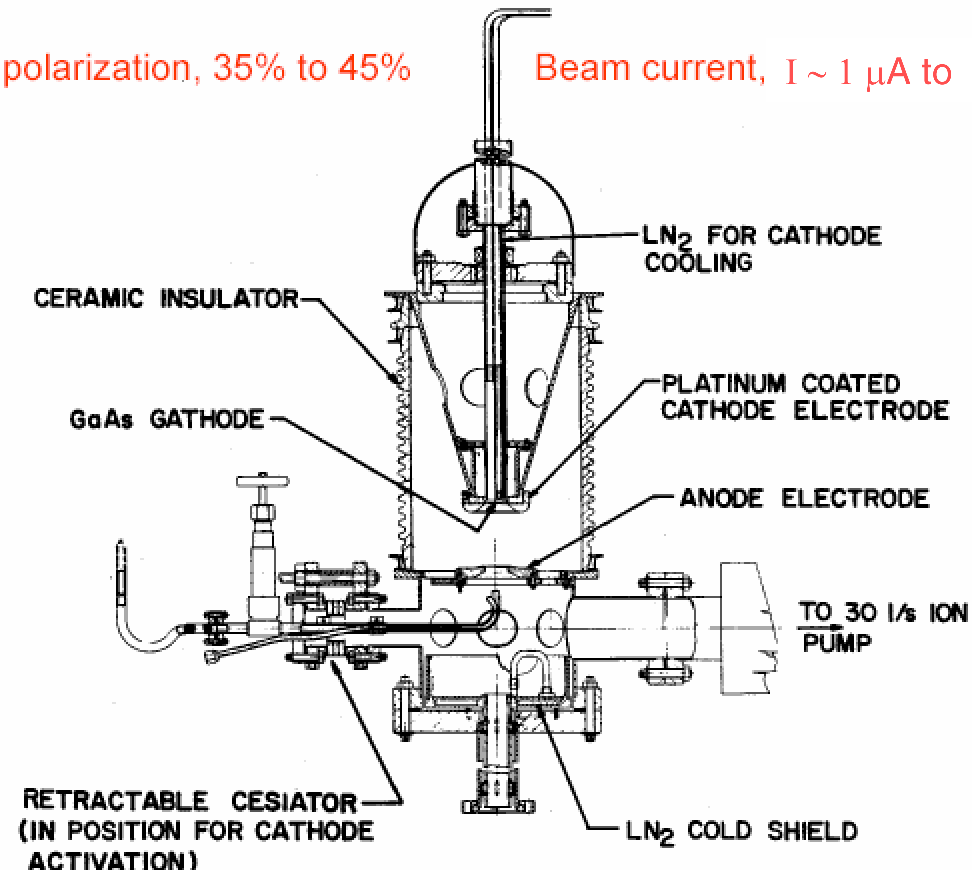
$$P = \frac{3-1}{3+1} = 50\%$$

First High Voltage GaAs Photogun

Polarized e⁻ Gun for SLAC Parity Violation Experiment

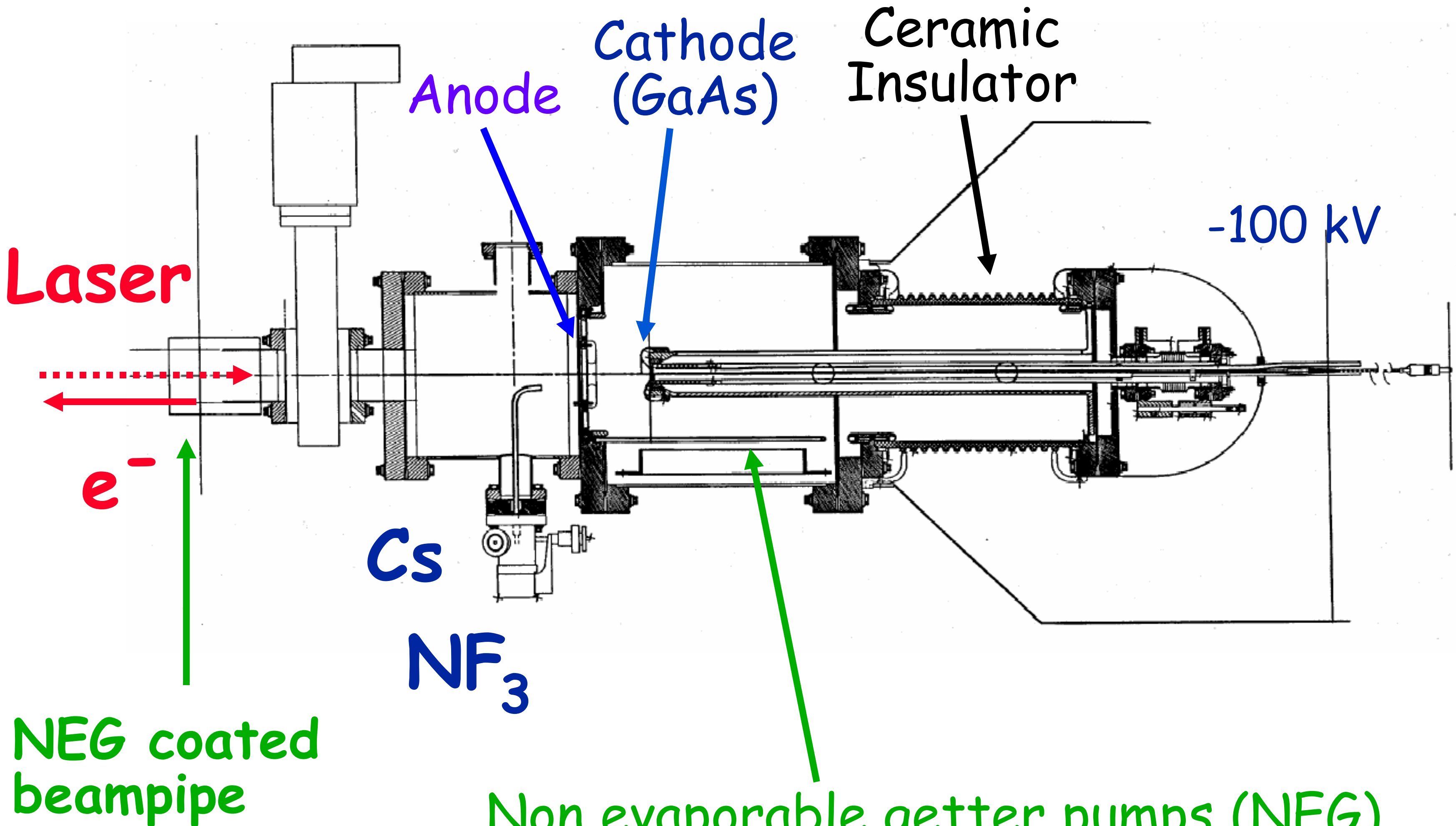
Beam polarization, 35% to 45%

Beam current, $I \sim 1\ \mu A$ to 15 A peak



Electrons into the accelerator Dec., 1977
Collaboration announces parity violation June, 1978

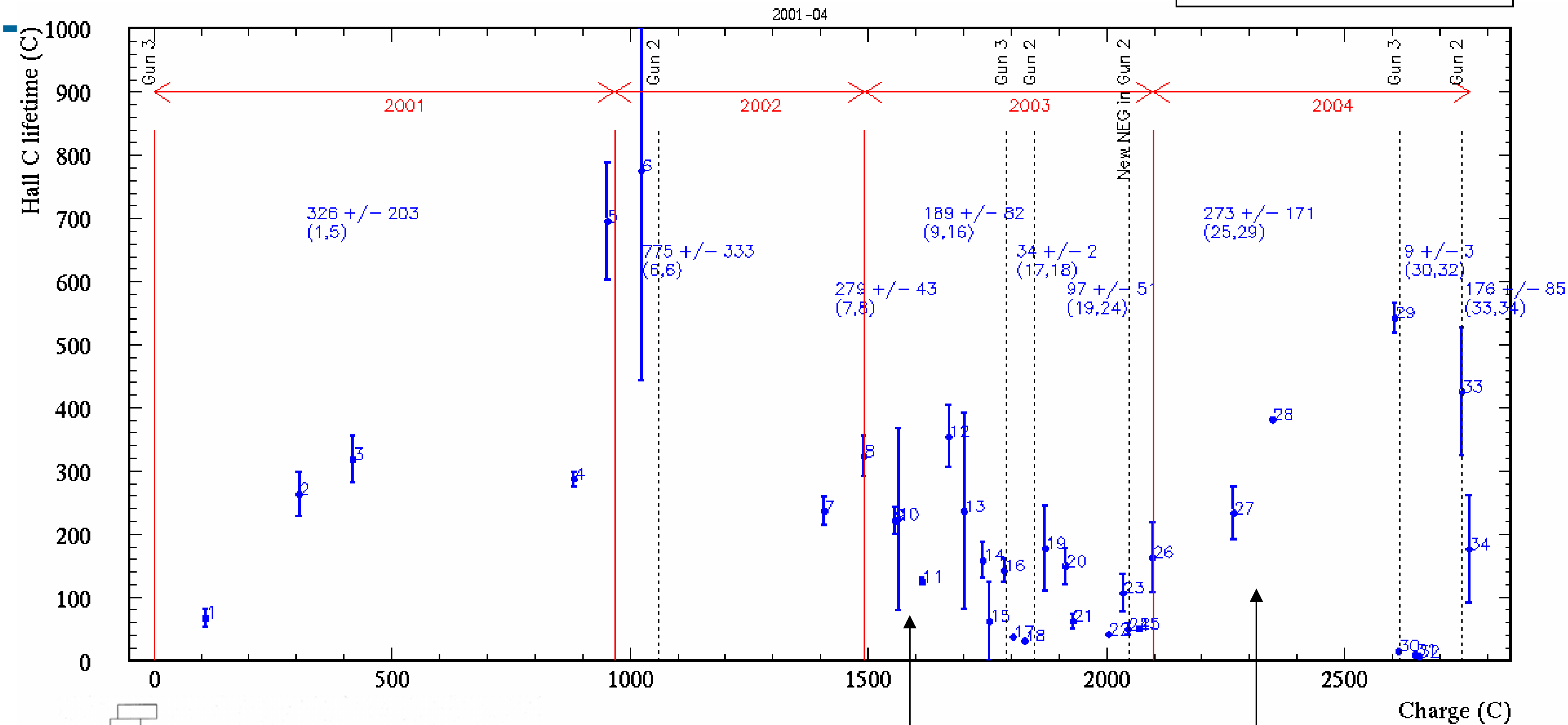
JLab gun design ~10 years later

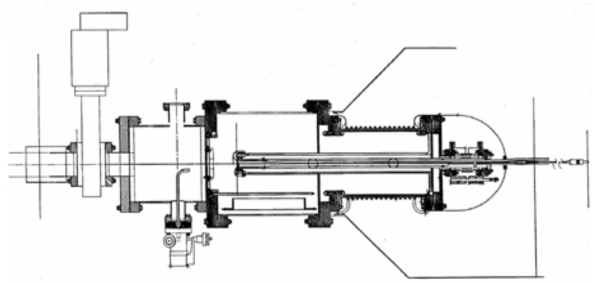


Non evaporable getter pumps (NEG)
4,000 liter/s pump speed ⇒ 5E-12 Torr

CEBAF Gun Charge Lifetime (2001-2004)

Data compiled by M. Baylac

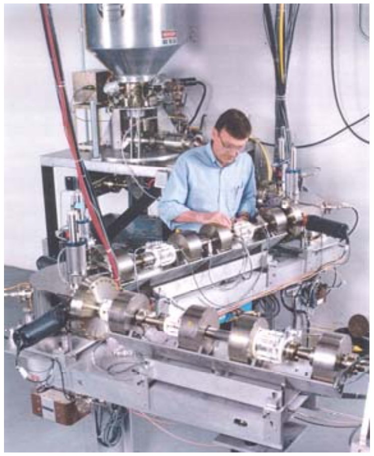




Charge Lifetime Steadily Decreasing

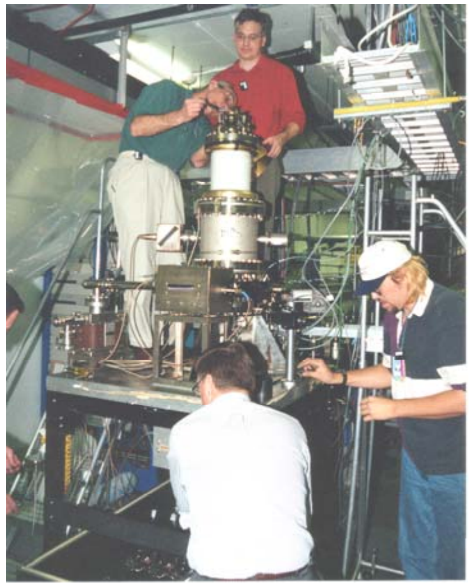
NEG replacement Summer 2003 improves lifetime

CEBAF Photoinjector



1997

1998

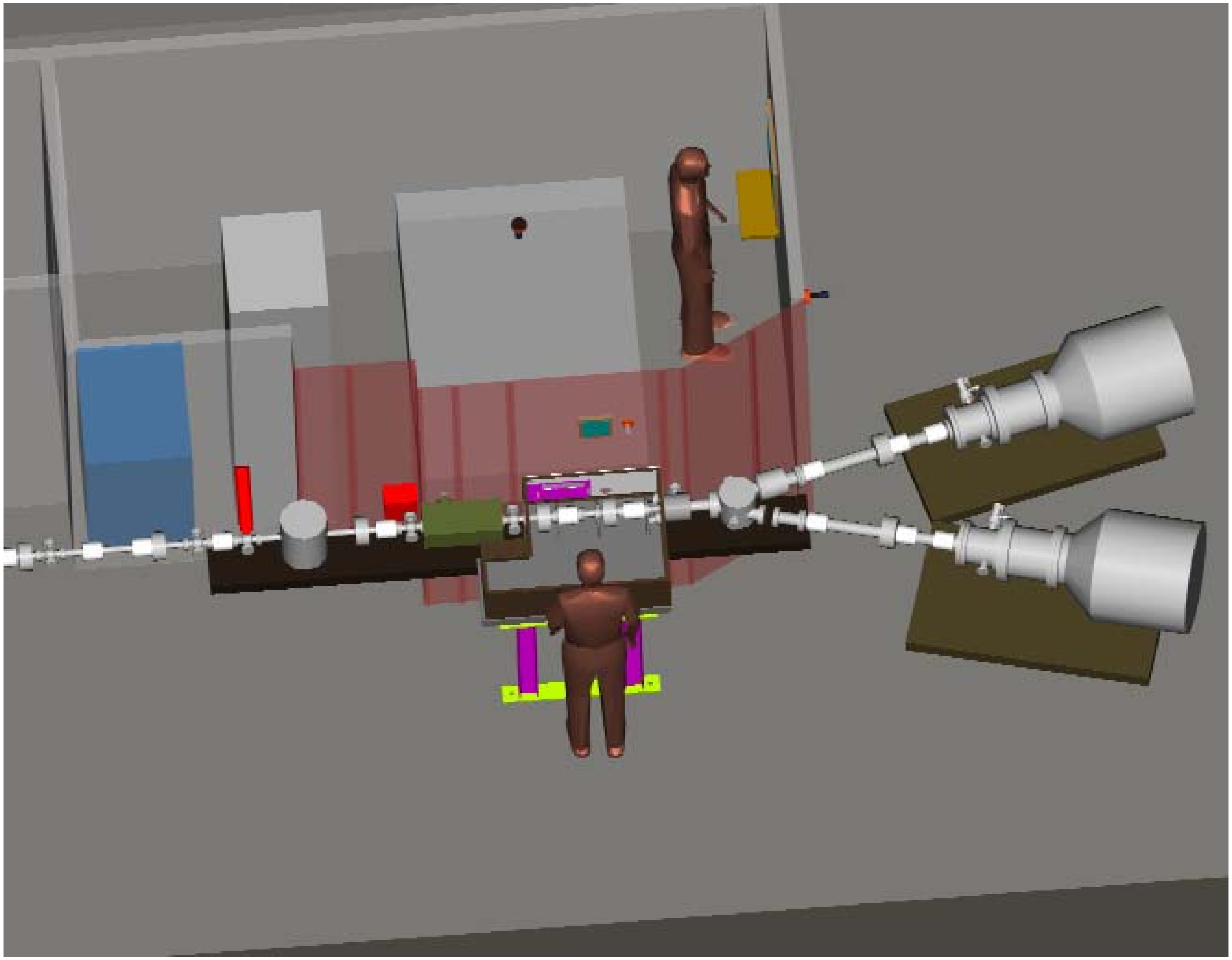


1999-2007

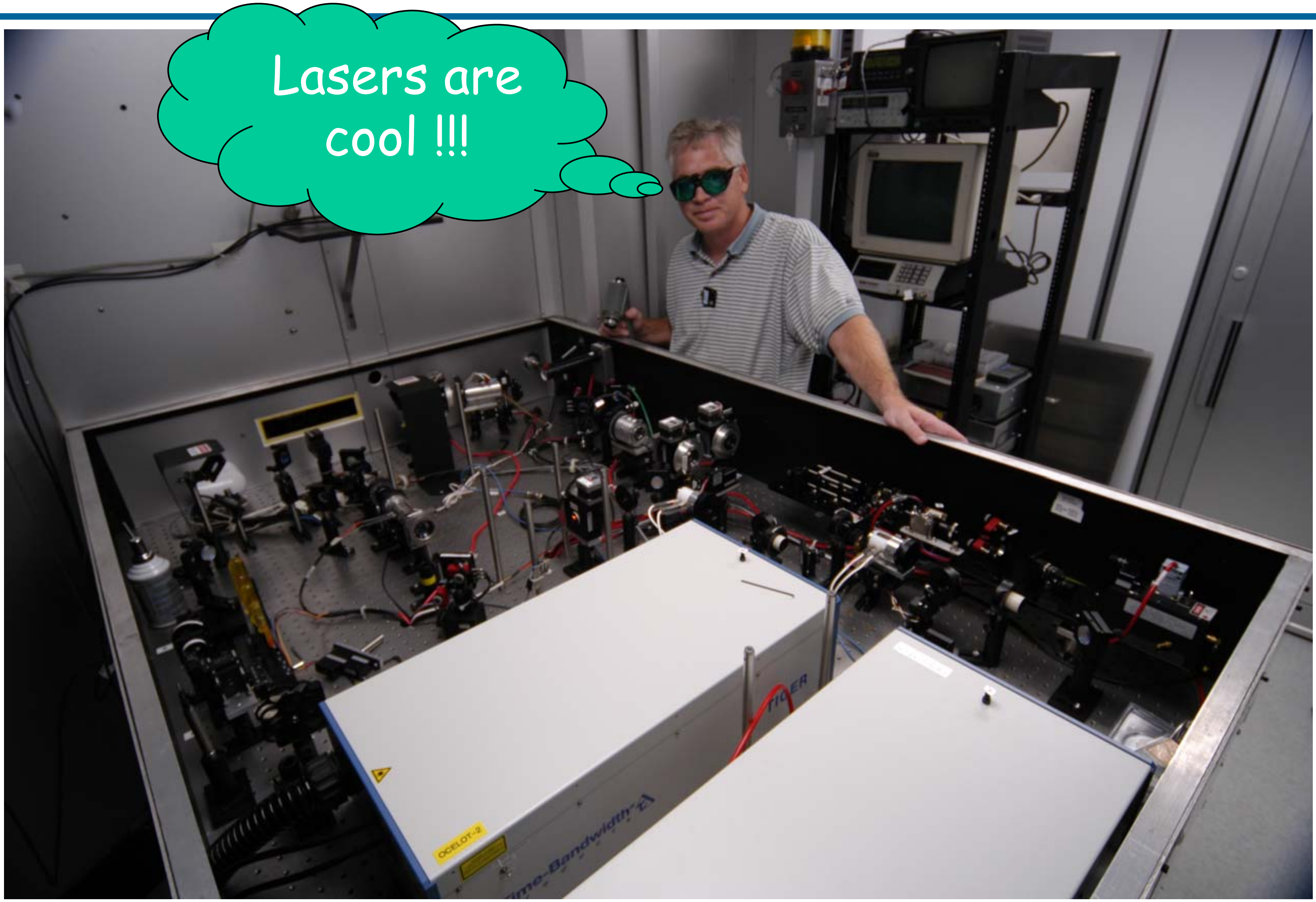
Long photocathode lifetime:
- Gun & Beamlines “NEG’s” => Good Vacuum
- No short focal length elements
- Photocathodes with anodized edge
- Synchronous photoinjection
- (Spare Gun)

What now … ???

“100 keV” Photoinjector



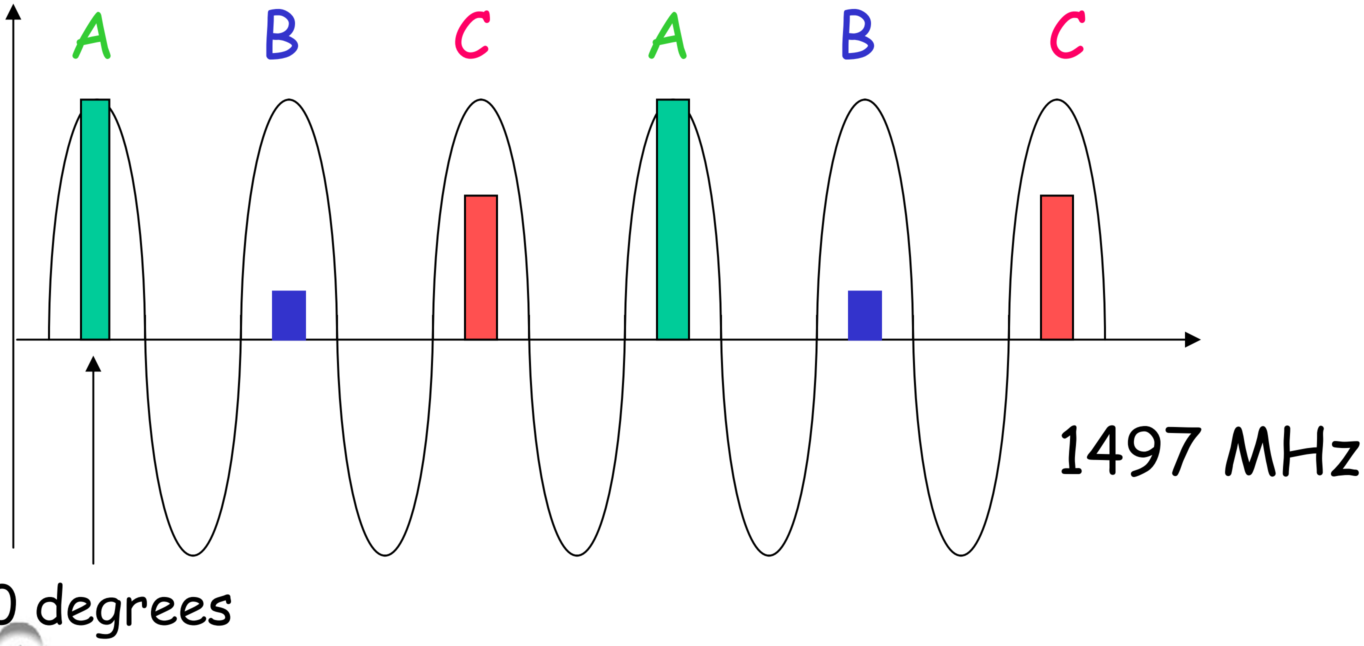
Laser Room for Dust & Climate Control



CEBAF Overview

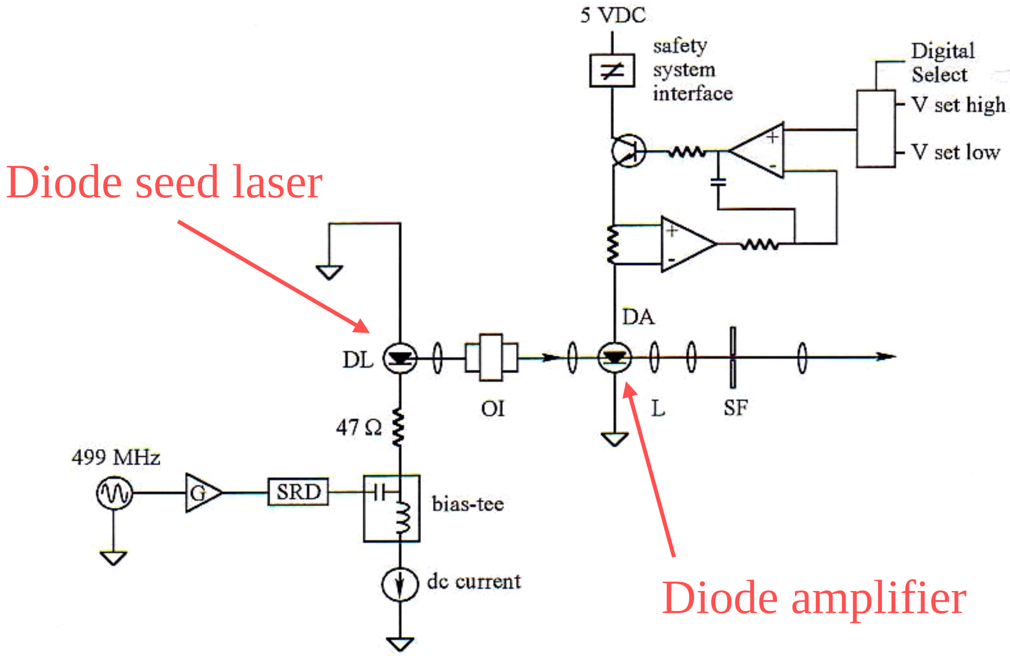
CEBAF Benefits;

- Recirculating LINACs
- Superconducting Cavities
- Three Halls = 3x the physics

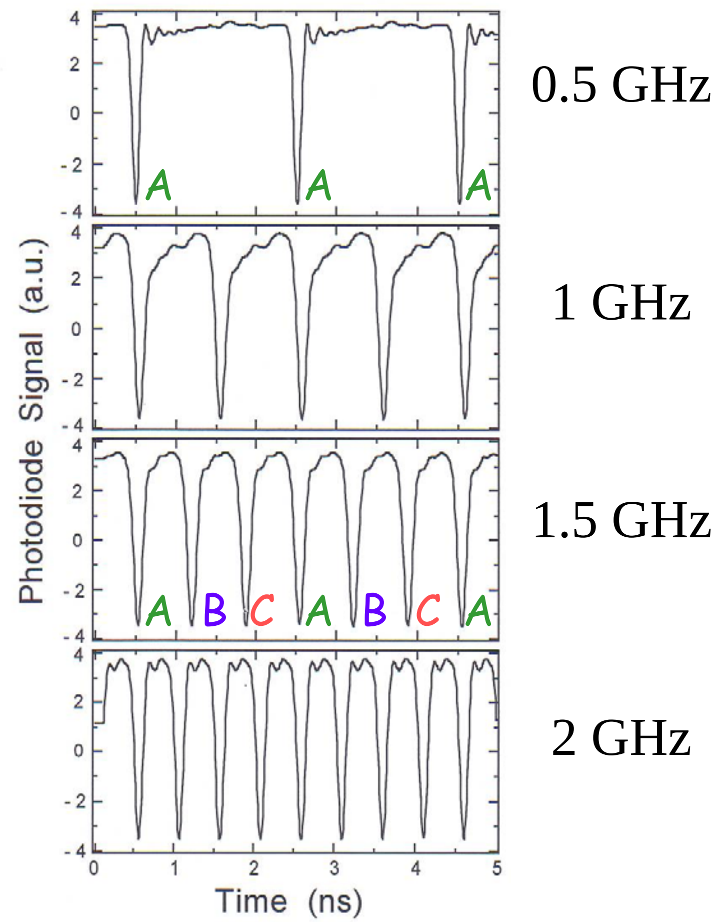


Radio Frequency Pulsed Lasers

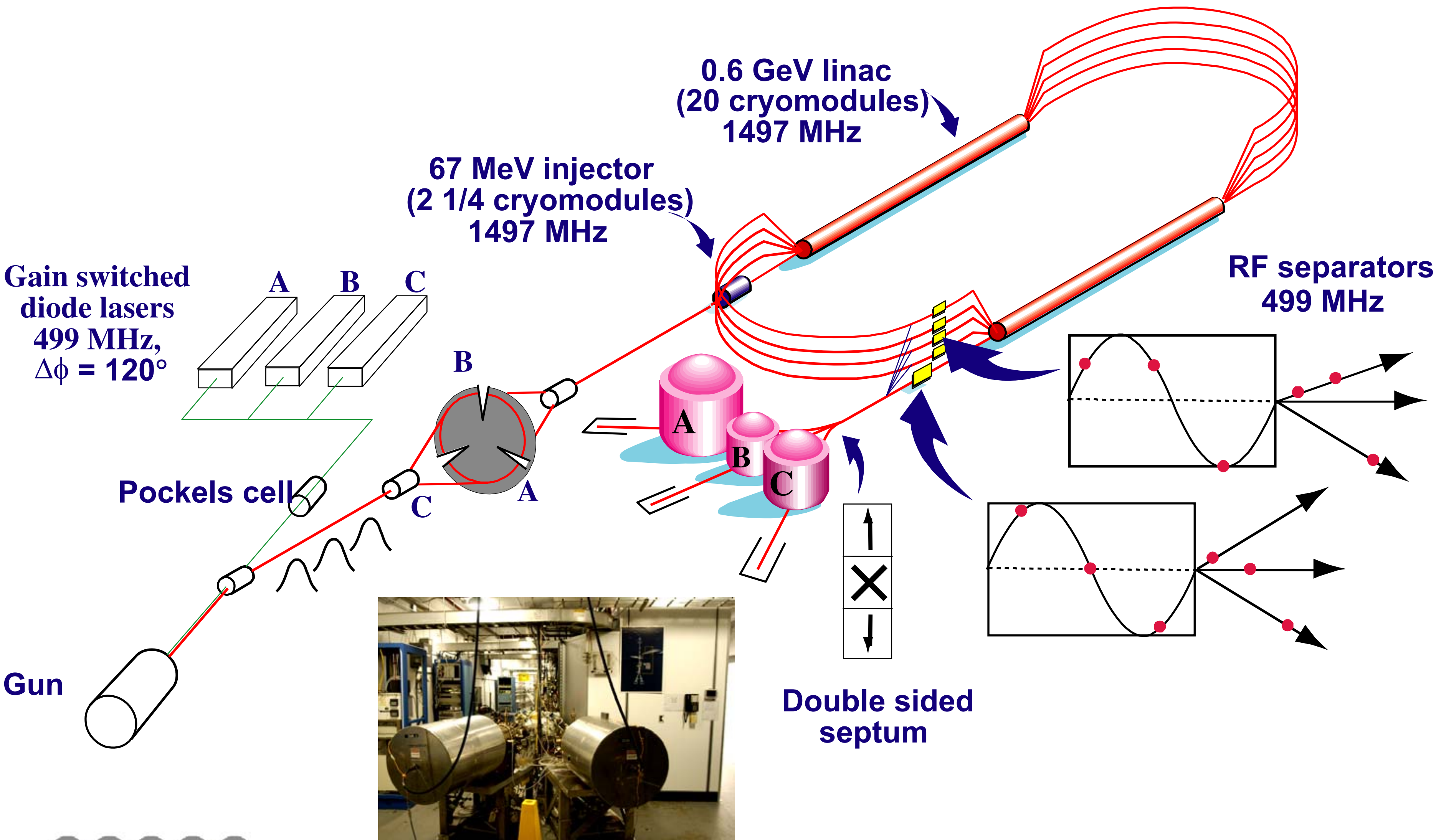
RF Gain Switching



M. Poelker, Appl. Phys. Lett. **67**, 2762 (1995).

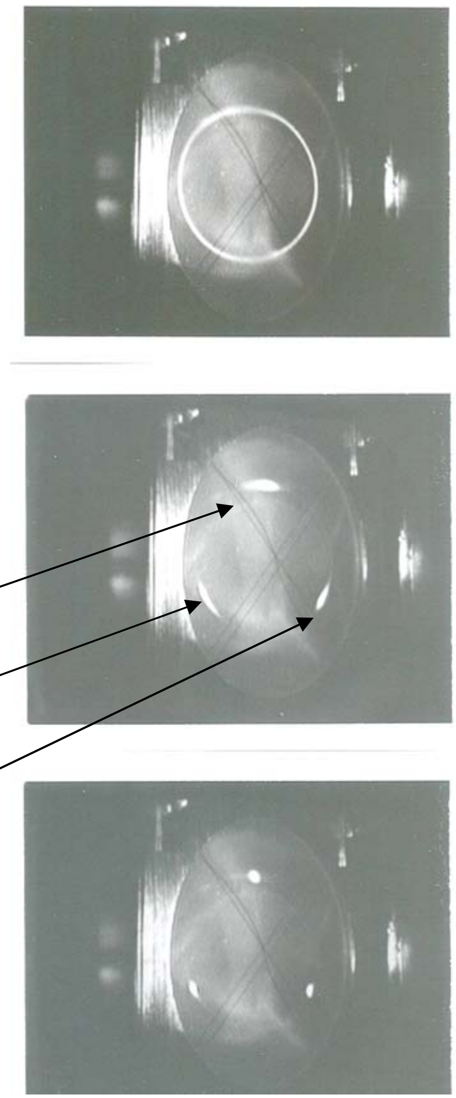


Continuous Electron Beam Accelerator Facility



Synchronous Photoinjection

Chopper viewer for three beams;

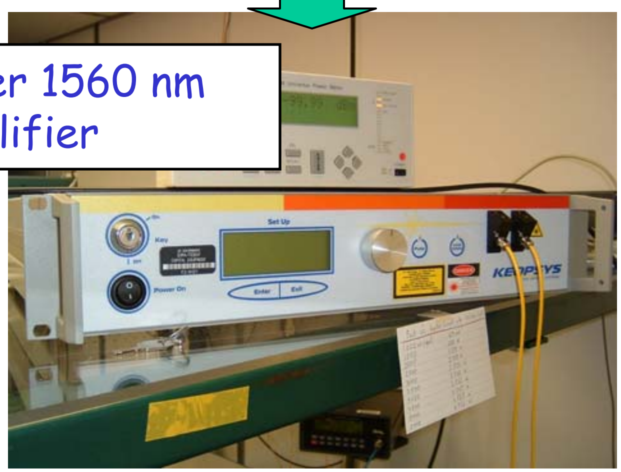


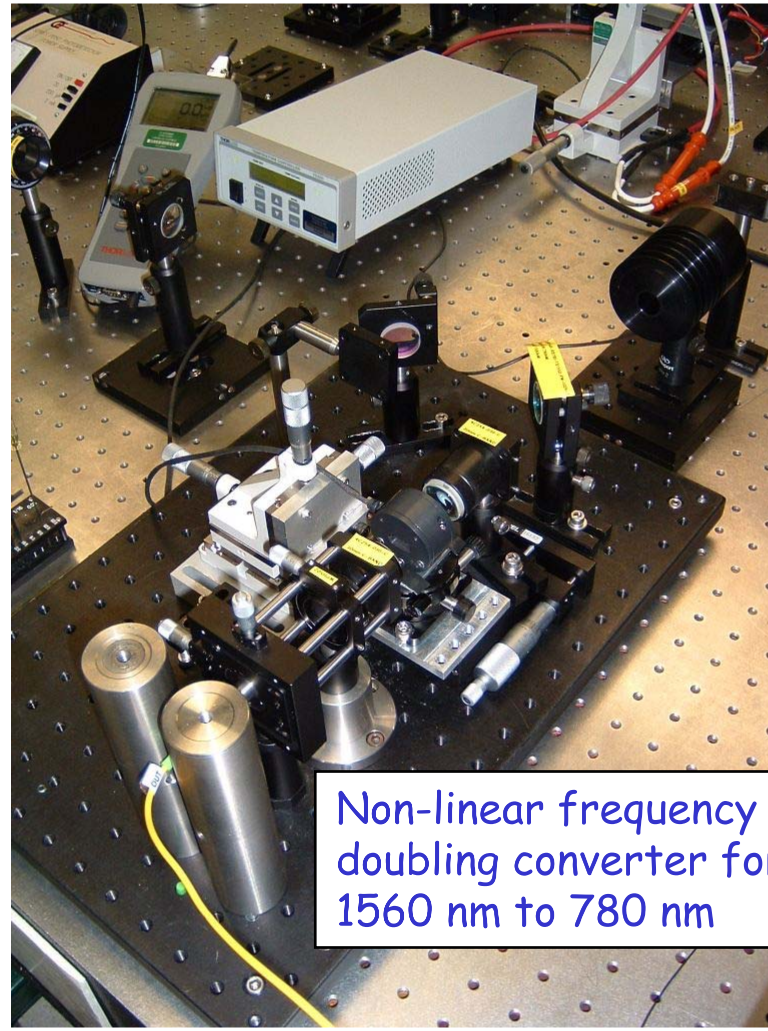
- DC Laser (wasted electrons)
- Pulsed laser (much better)
- PreBuncher (even better)

New fiber technology-based laser system

RF locked low-power
1560 nm fiber diode

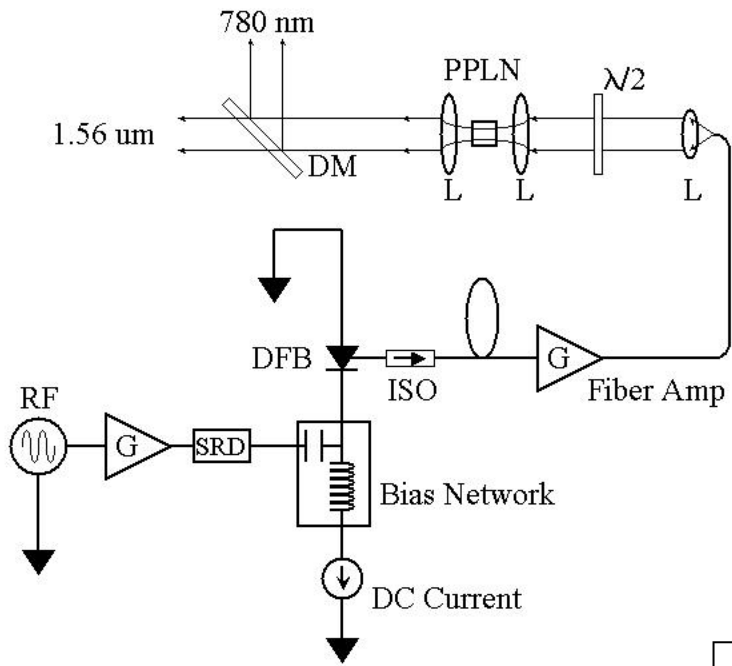
High power 1560 nm
fiber amplifier

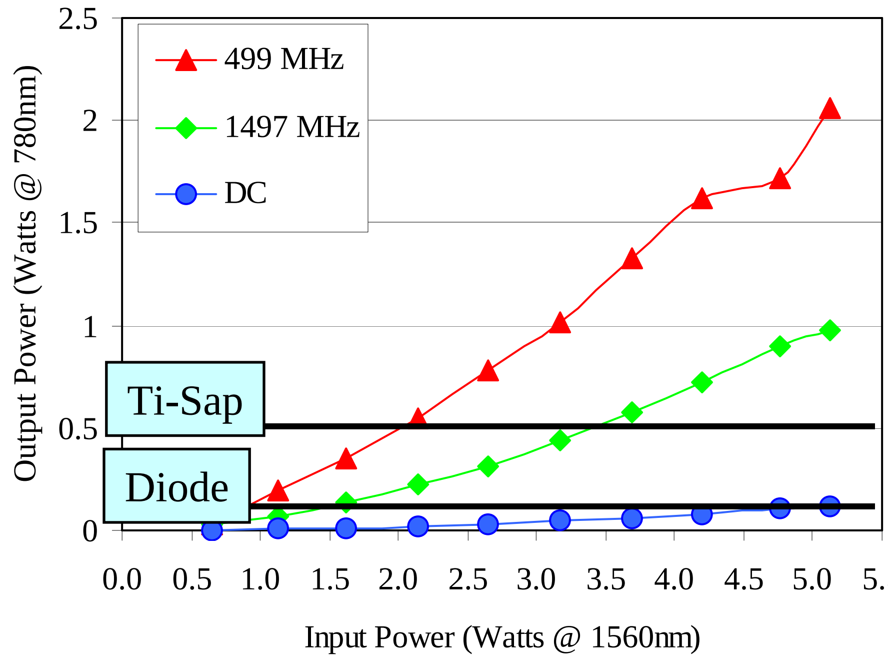




Non-linear frequency
doubling converter for
1560 nm to 780 nm

New Fiber-Based Drive Laser

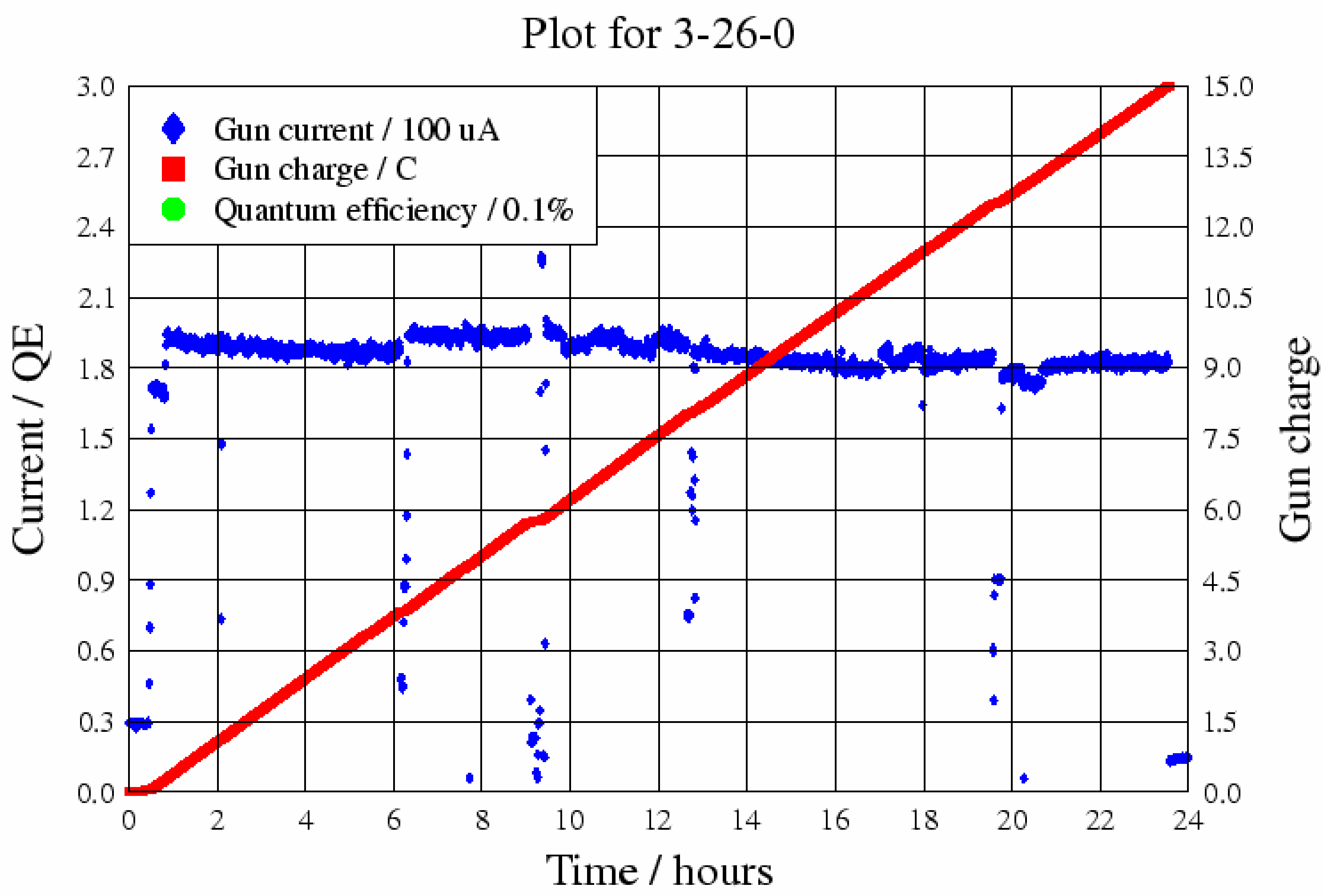




J. Hansknecht and M. Poelker, Phys. Rev. ST Accel. Beams 9, 063501 (2006)

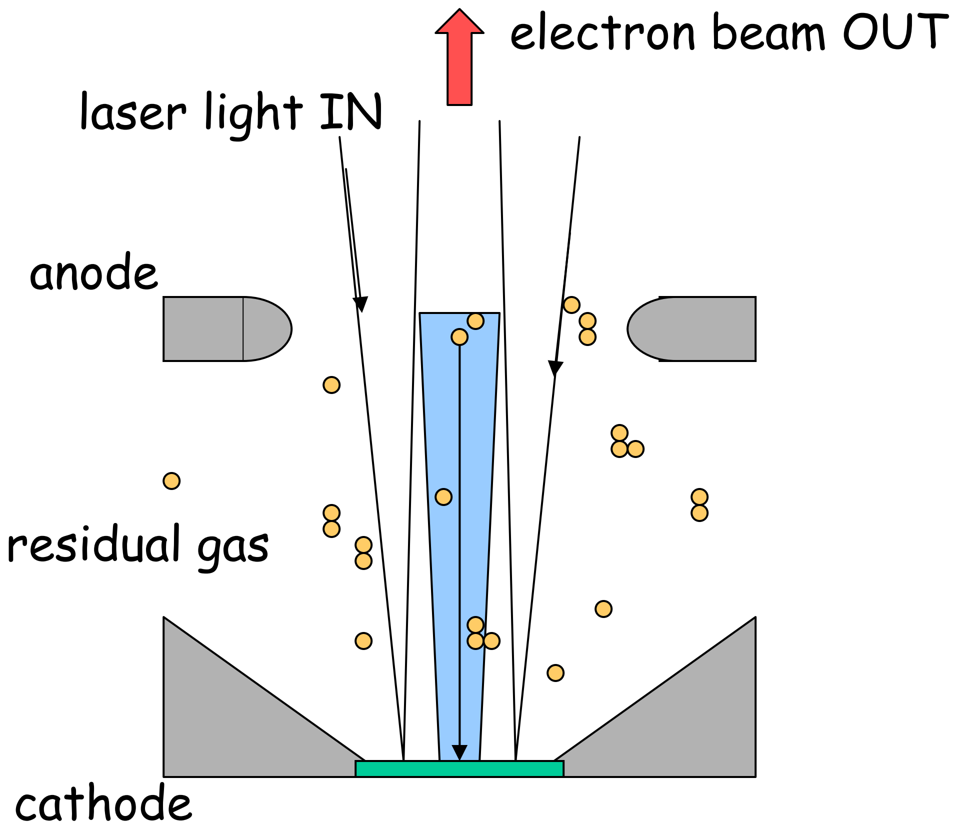
- Gain-switching better than modelocking; no phase lock problems
- Very high power
- Telecom industry spurs growth, ensures availability
- Useful because of superlattice photocathode (requires 780nm)

Who wants polarized electrons?

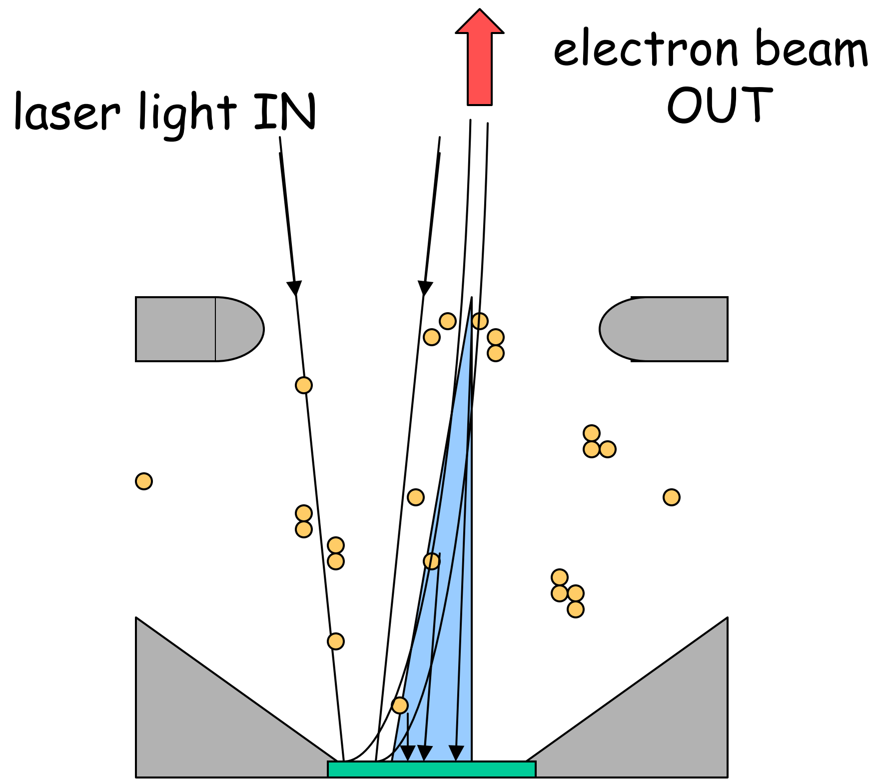


Ion Back-Bombardment

High energy ions focused to electrostatic center



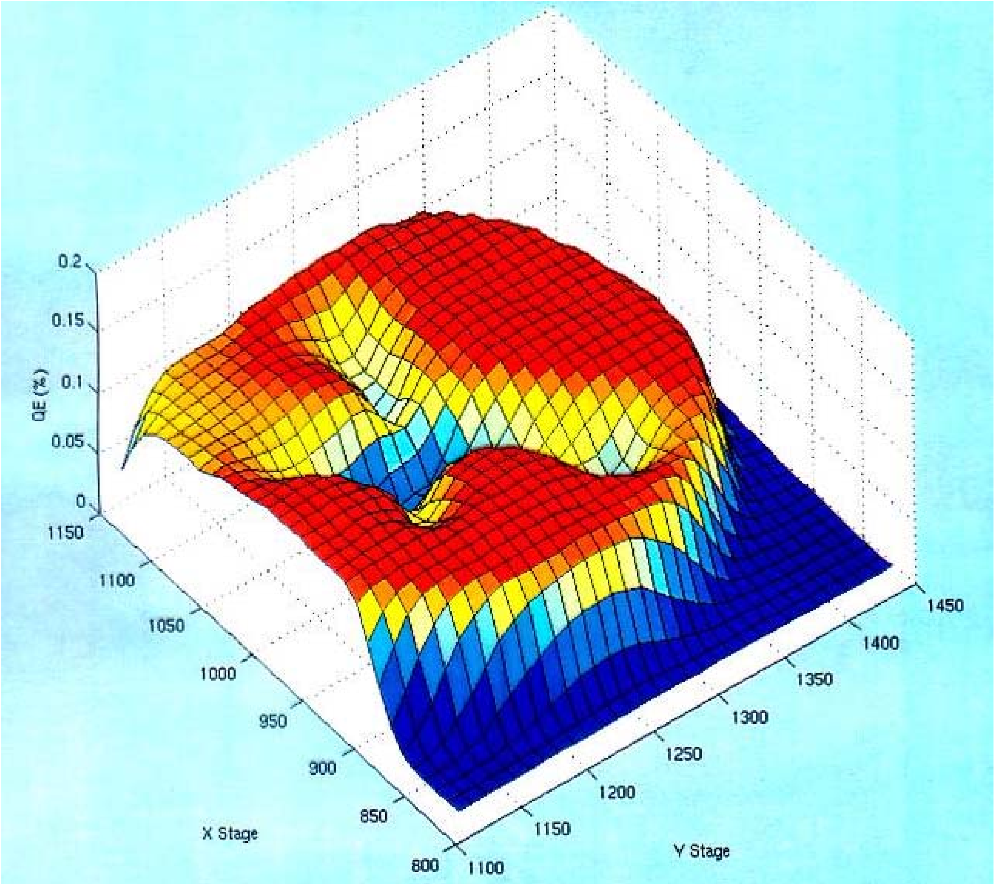
We don't run beam from electrostatic center

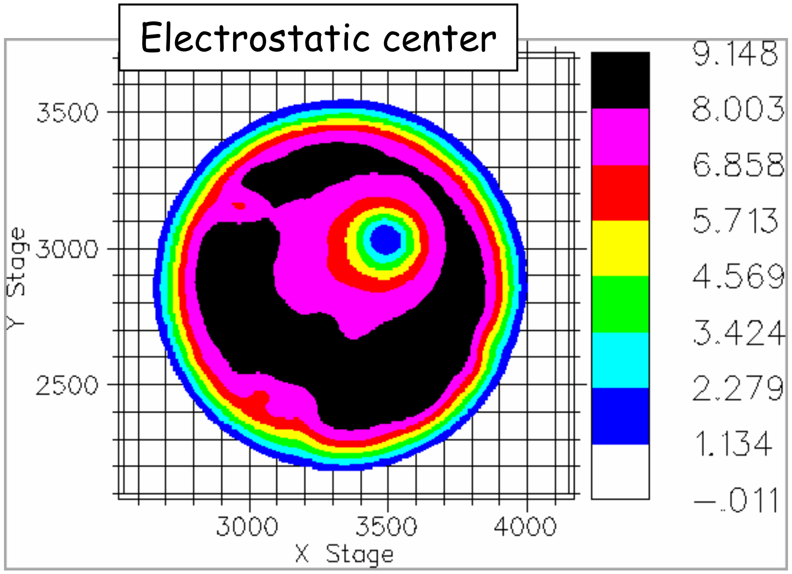


Ions create QE trough to electrostatic center

Bad, bad ions…

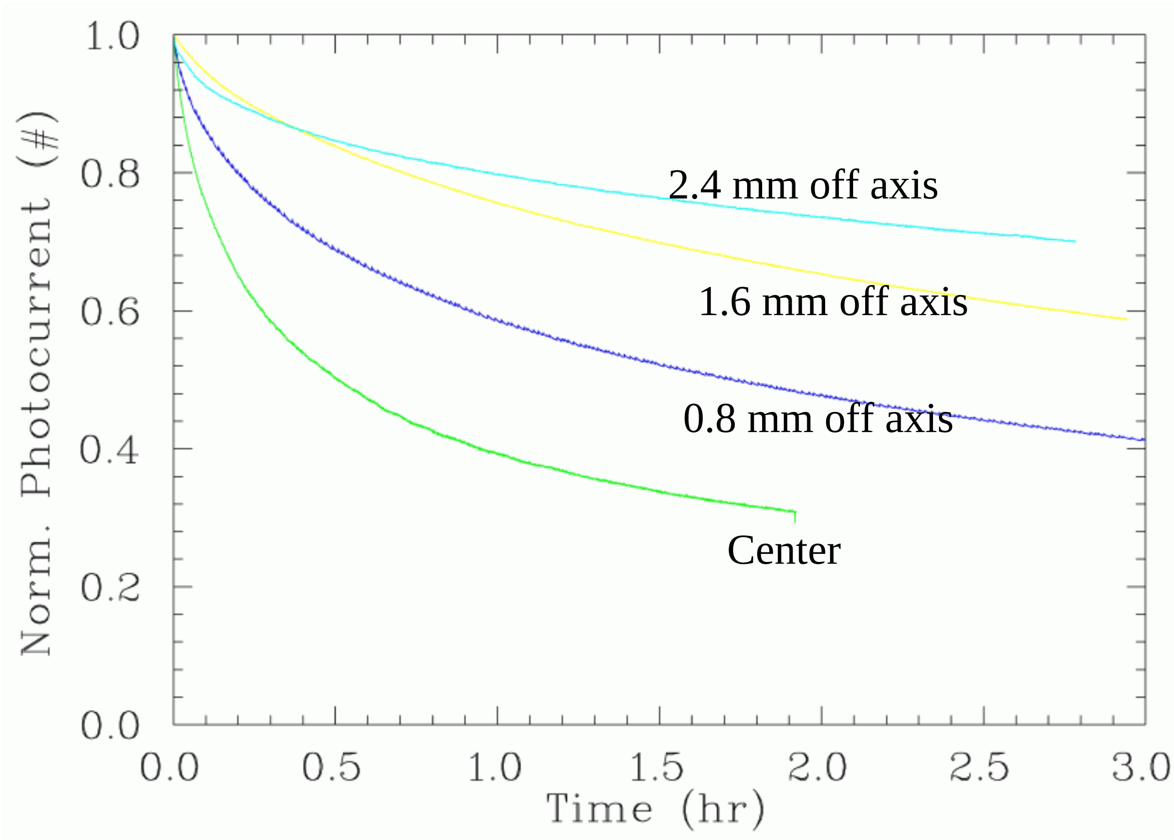
Imperfect vacuum => QE degrades via ion backbombardment



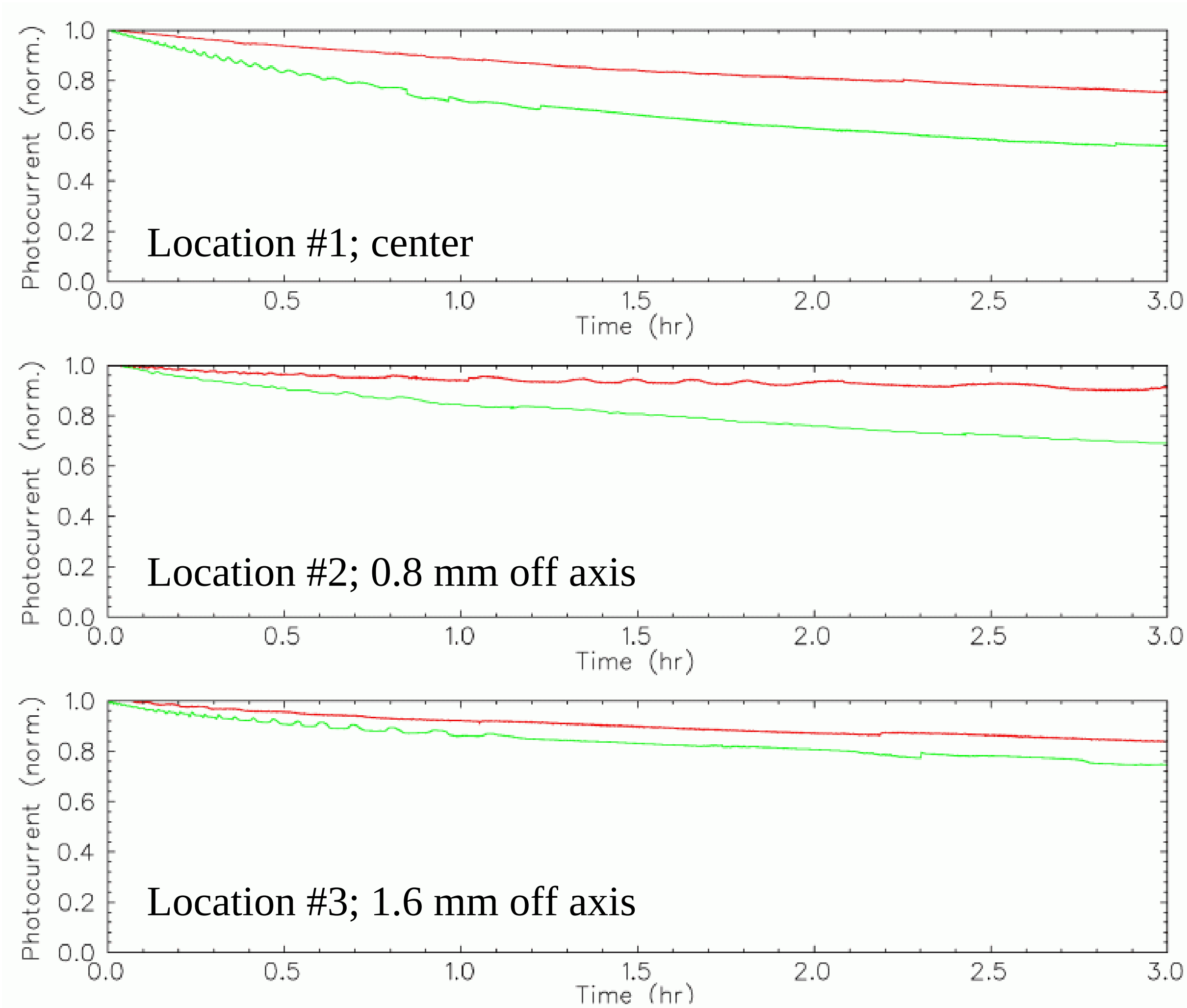


Lifetime vs. Beam Location

Ionized gas is attracted toward the electrostatic center of photocathode
Solution => position laser spot (e- beam location) off axis



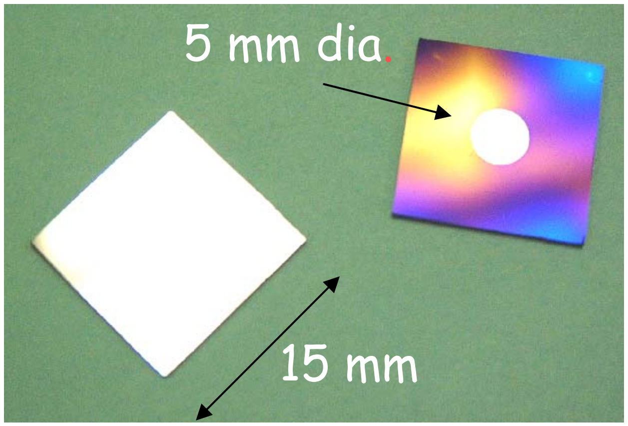
Exposed Active Area



5mm (red)

11 mm (green)

Limiting Active Area



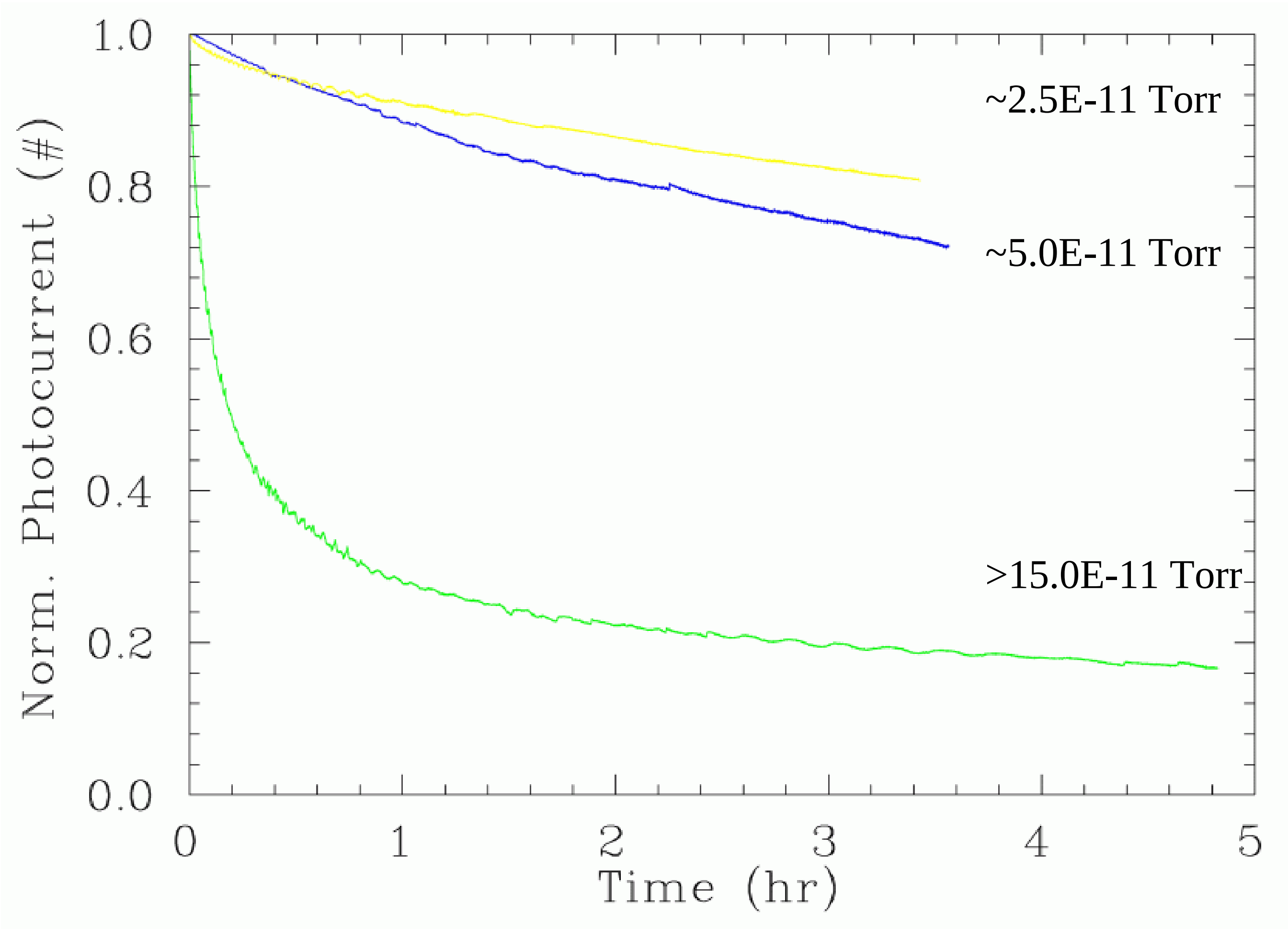
Anodize photocathode in electrolytic bath of weak phosporic acid.

Photocathode "out of box"

Electrons emitted from edge of wafer hit vacuum chamber walls. This is bad for vacuum.

Anodization eliminates inadvertent photoemission from locations not intentionally illuminated with laser light.

Better Vacuum = Longer Lifetime



We understand Alice's worry…

The woods were dark and foreboding, and Alice sensed that sinister eyes were watching her every step. Worst of all, she knew that Nature abhorred a vacuum.

The woods were dark and foreboding, and Alice sensed that sinister eyes were watching her every step. Worst of all, she knew that Nature abhorred a vacuum

Vacuum regimes

- Low, Medium Vacuum (>10^{-3} Torr)
  - Viscous flow
    - interactions between particles are significant
  - Mean free path less than 1 mm
- High, Very High Vacuum (10^{-3} to 10^{-9} Torr)
  - Transition region
- Ultra High Vacuum (10^{-9} - 10^{-12} Torr)
  - Molecular flow
    - interactions between particles are negligible
    - interactions primarily with chamber walls
  - Mean free path 100-10,000 km
- Extreme High (<10^{-12} Torr)
  - Molecular flow
  - Mean free path 100,000 km or greater

Air ~ 10^{16} / Torr-cm^3

Vacuum Conditions at CEBAF

Application	Pressure Range	Location	Vacuum Regime
Beamline to dumps	10^{-5} Torr	Target to dump line	Medium
Insulating vacuum for cryogens	10^{-4} Torr to 10^{-7} Torr	Cryomodules, transfer lines	Medium to high
Targets, Scattering Chambers	10^{-6} to 10^{-7} Torr	Experimental Halls	High to very high
RF waveguide warm to cold windows	10^{-7} to 10^{-9} Torr	Between warm and cold RF windows	High to very high
Warm beamline vacuum	10^{-7} to 10^{-8} Torr or better	Arcs, Hall beamline, BSY, some injector	High to very high
Warm region girders	10^{-9} Torr or better	Girders adjacent to cryomodules	Very high to ultrahigh
Differential pumps	Below 10^{-10} Torr	Ends of linacs, injector cryomodules and guns	Ultrahigh vacuum
Baked beamline	10^{-10} to 10^{-11}Torr	Y chamber, Wien filter, Pcup	Ultra high vacuum
Polarized guns	10^{-11} to 10^{-12} Torr	Inside Polarized guns	Ultra high vacuum
SRF cavity vacuum	Well below 10^{-12} Torr	Inside SRF cavities with walls at 2K	Extreme high vacuum

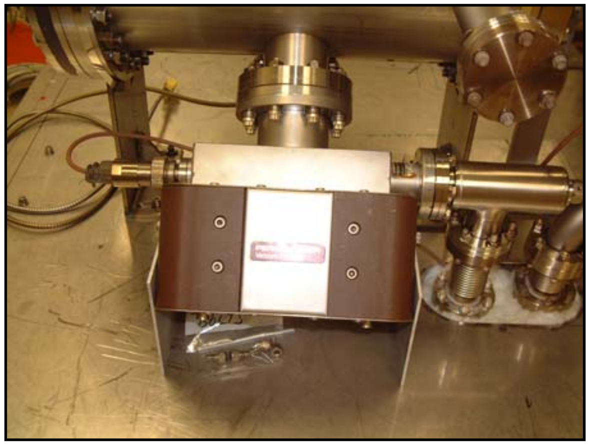
Where does the gas come from?

- Outgassing from the system
  - Metal and non-metal (viton o-rings, ceramics) all outgas
  - Primarily water in unbaked systems
  - Primarily hydrogen from steel in baked systems
- Leaks
  - Real
    - Gaskets not sealed
    - Cracks in welds, bellows, ceramics, window joints
    - Superleaks that only open at very low temperatures
  - Virtual
    - Small volumes of gas trapped inside system (screw threads, etc.) that pump out slowly over time
- Gas load caused by the beam
  - Desorption of gases by elevated temperatures, electrons or photons striking surfaces, etc.
- Loads (targets, etc.) where gas is added
- Permeation of gasses through materials
  - Viton gaskets worse than metal seals
  - Hydrogen can permeate through stainless steel!

Ultra High Vacuum Pumps

- Getter Pumps
  - Chemically active surface
    - Titanium sublimed from hot filament
    - Non-Evaporative Getters
  - Molecules stick when they hit
    - Does not work well for inert gasses such as Argon, Helium or for methane
- Ion Pumps
  - Electric field to ionize gasses
  - Magnetic field to direct gasses into cathodes where they are trapped
    - Has some pumping capability for noble gasses
- Baking used to get pressures below 10^{-10} Torr
  - 250°C for 30 hours removes water vapor bonded to surface that otherwise limits pressure
- Contamination by oil from roughing pumps, fingerprints, machining residue must be avoided!!!

NEG pump array

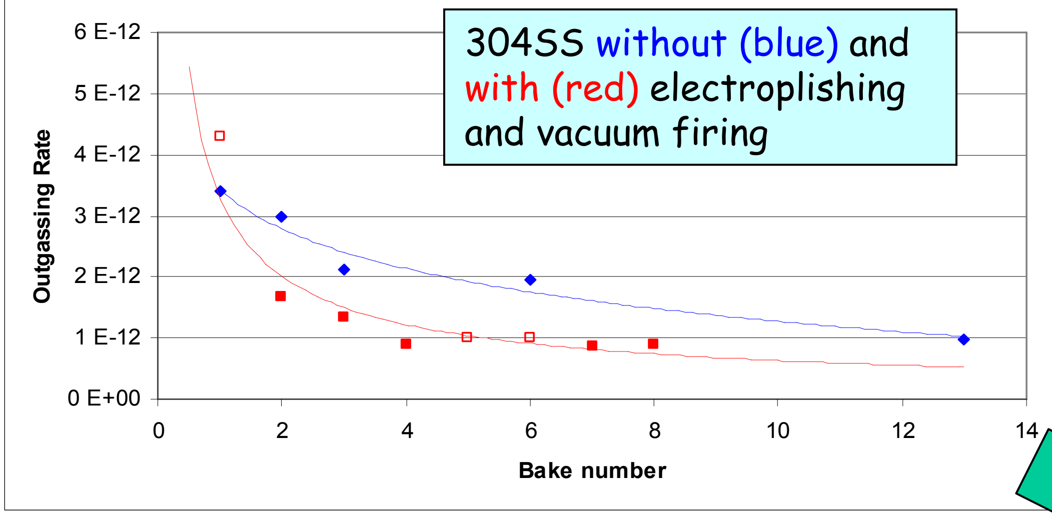


Ion Pump

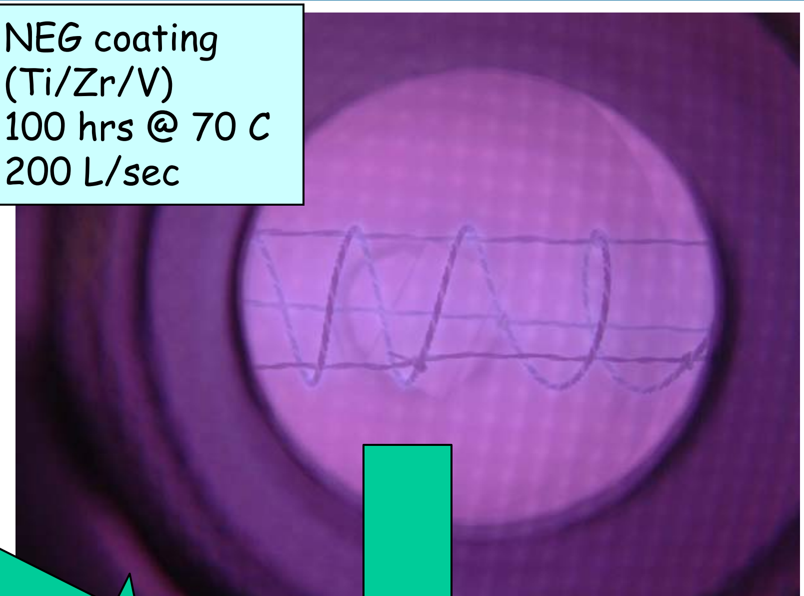
Improvements to the High Voltage Chamber Vacuum

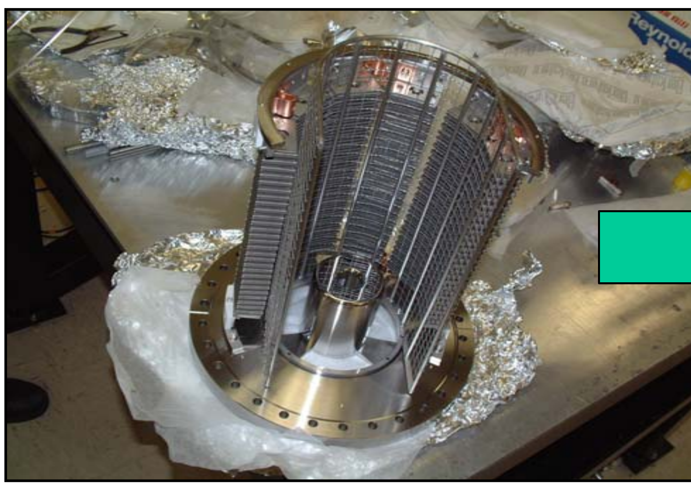
304 SS: Electropolished & Vacuum Fired
(AVS: 3 hrs @ 900 C @ 3×10^{-6} T)

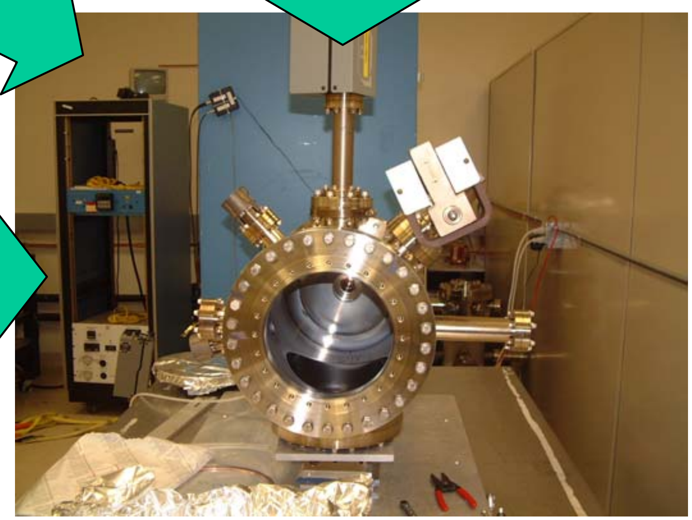
304SS without (blue) and with (red) electroplishing and vacuum firing



NEG coating
(Ti/Zr/V)
100 hrs @ 70 C
200 L/sec





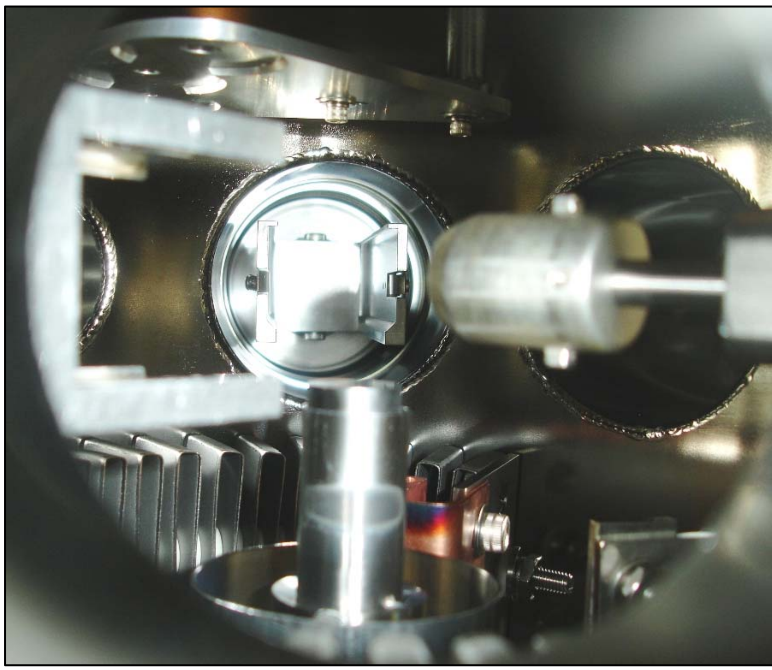


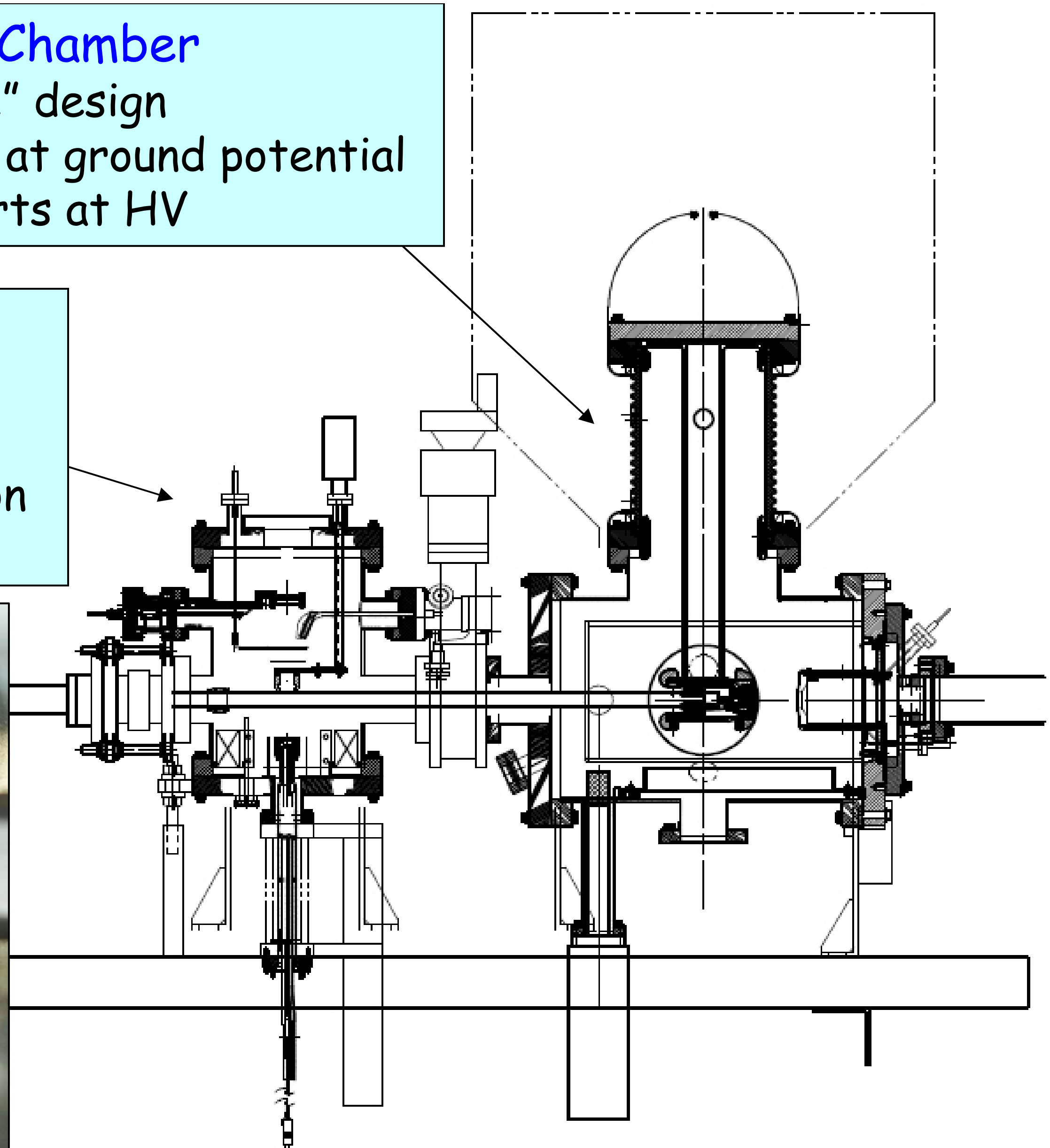
High Voltage Chamber

- "Side ceramic" design
- load chamber at ground potential
- No moving parts at HV

Activation Chamber

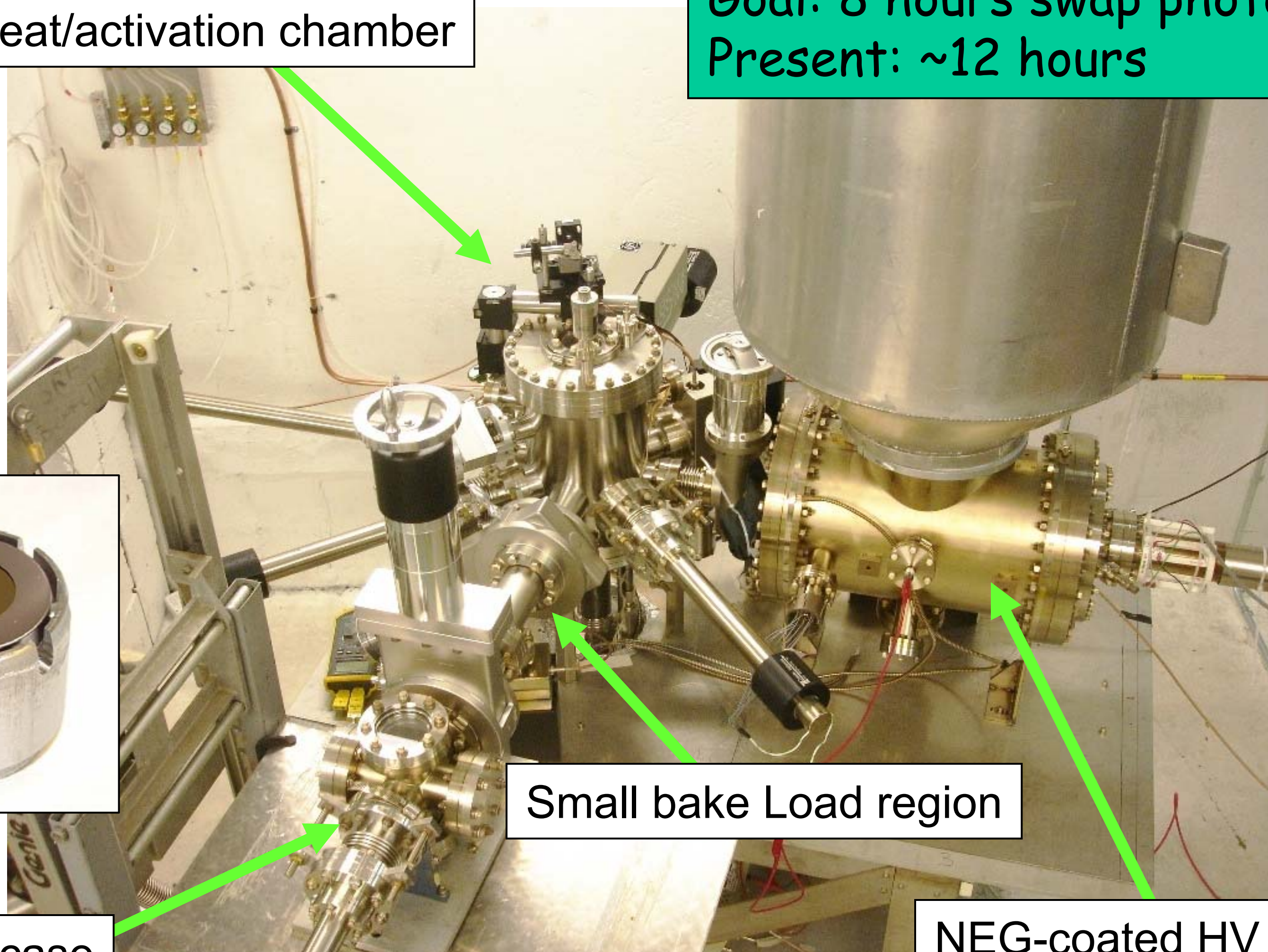
- Mini-stalk heater
- Mask selects active area
- UHV IP supplies gauge activation
- Keyed & eared pucks



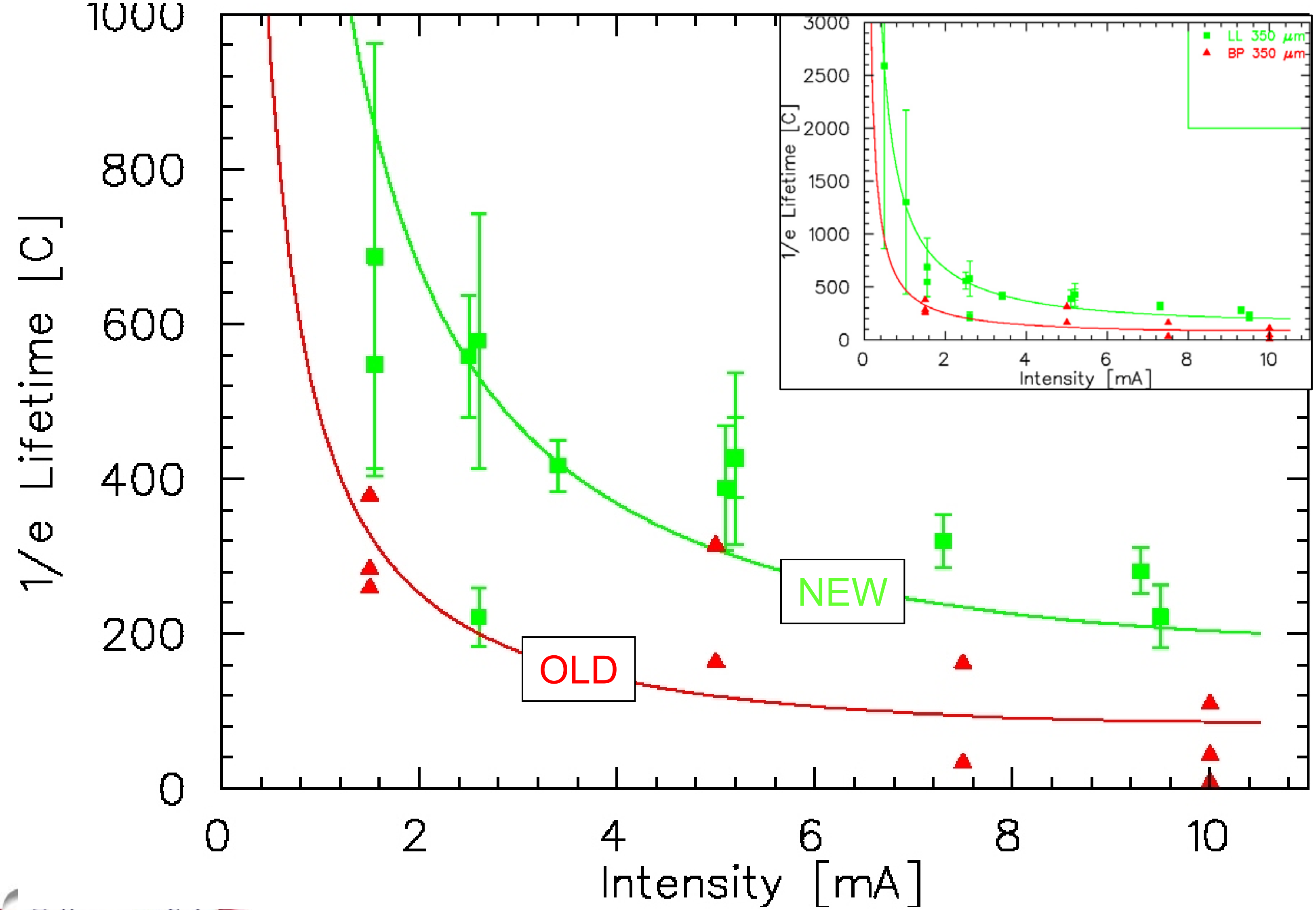


New Load Lock Gun in Test Stand Spring '06

Goal: 8 hours swap photocathode
Present: ~12 hours

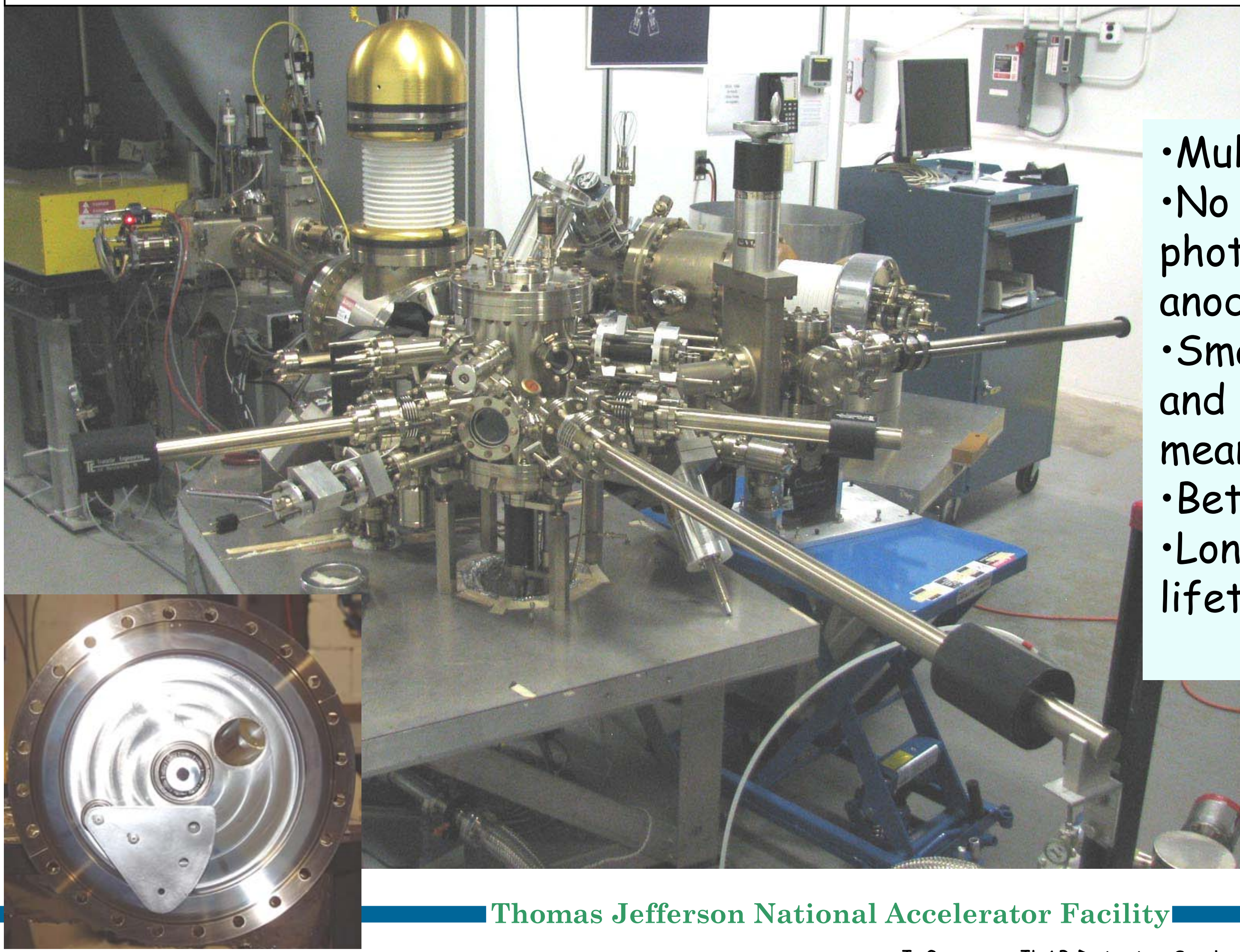


NEW CEBAF Load Lock Gun vs. "OLD" Load Lock Gun



NEW CEBAF Load Locked Gun

No more gun bakeouts!   Photocathode replaced in 8 hours versus 4 days.



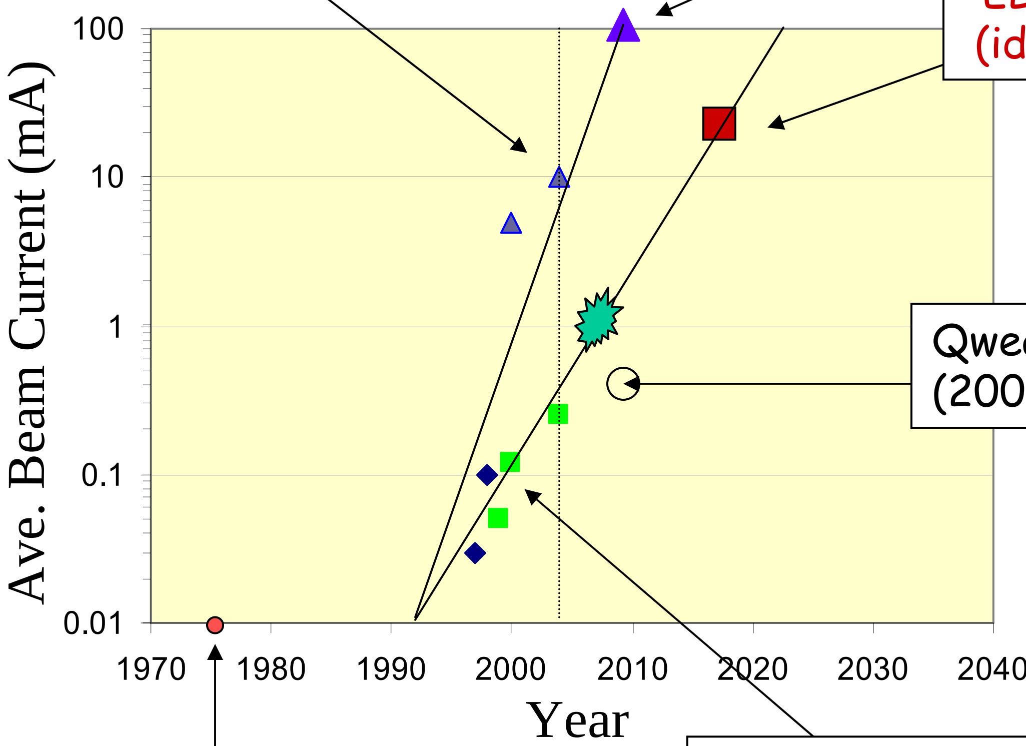
- Multiple samples,
- No more photocathode edge anodizing,
- Smaller surface area and no more venting means:
- Better gun vacuum,
- Longer photocathode lifetime

GaAs Trending Higher Average Current

JLab FEL program with unpolarized beam

Cornell/JLab (construction)

ELIC (idea)



Qweak (2009)

First polarized beam from GaAs photogun

First low polarization, then high polarization at CEBAF