Polarized Electron Sources @ JLAB

WebPage - www.jlab.org/accel/inj_group

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- James McCarter (University of Virginia)
- Ken Surles-Law (Hampton University, JLab staff)
- Alicia Hofler (Old Dominion University, JLab staff)

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*

HUGS

June 6, 2008

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)

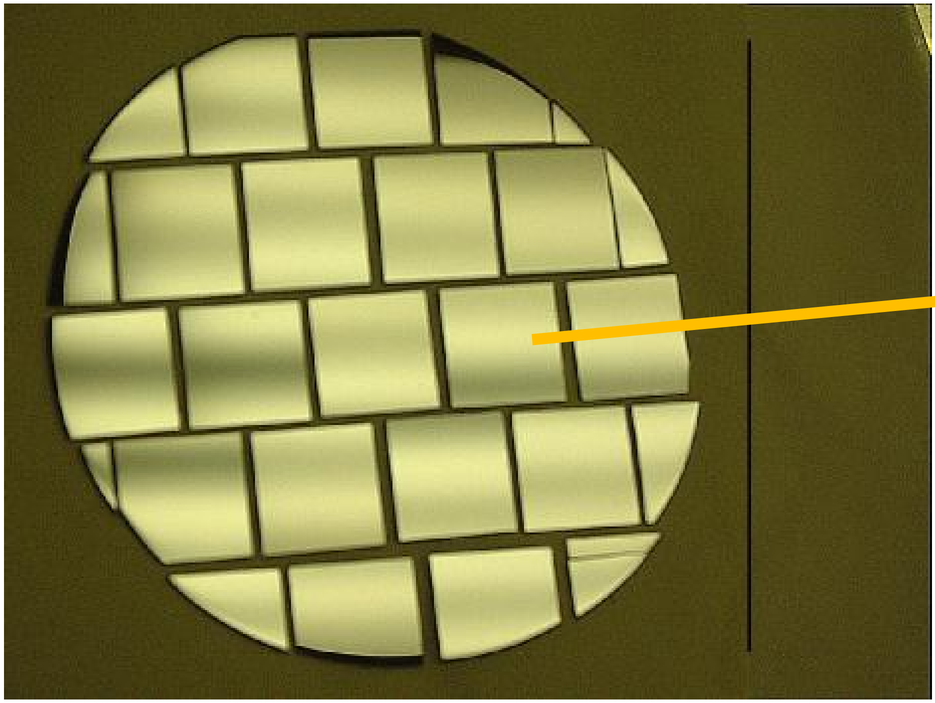
Many accelerator facilities have had polarized e- GaAs sources:

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

1980 ~ 1 microAmp .... 2000 ~ 100 microAmp .... 2010 ~ milliAmp ??

Gallium Arsenide

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



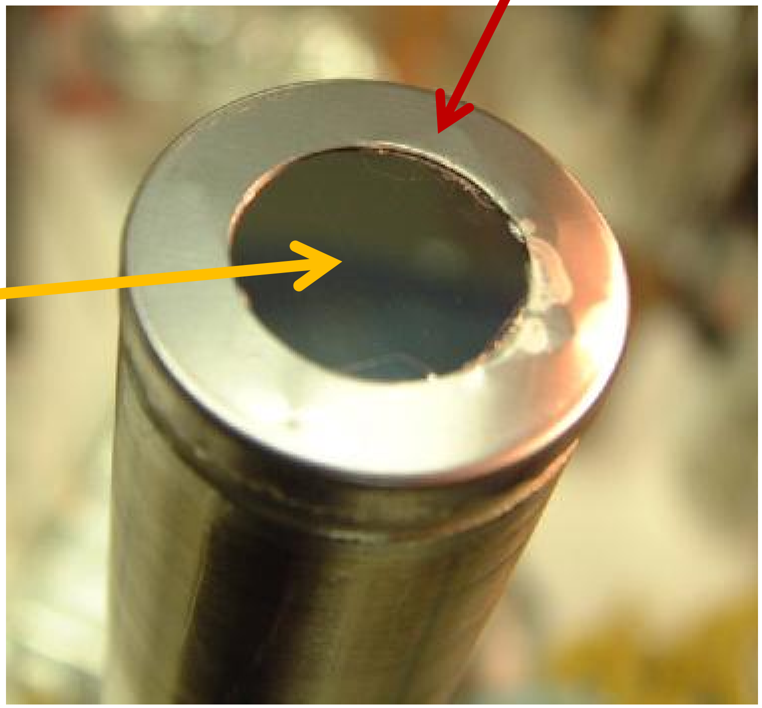
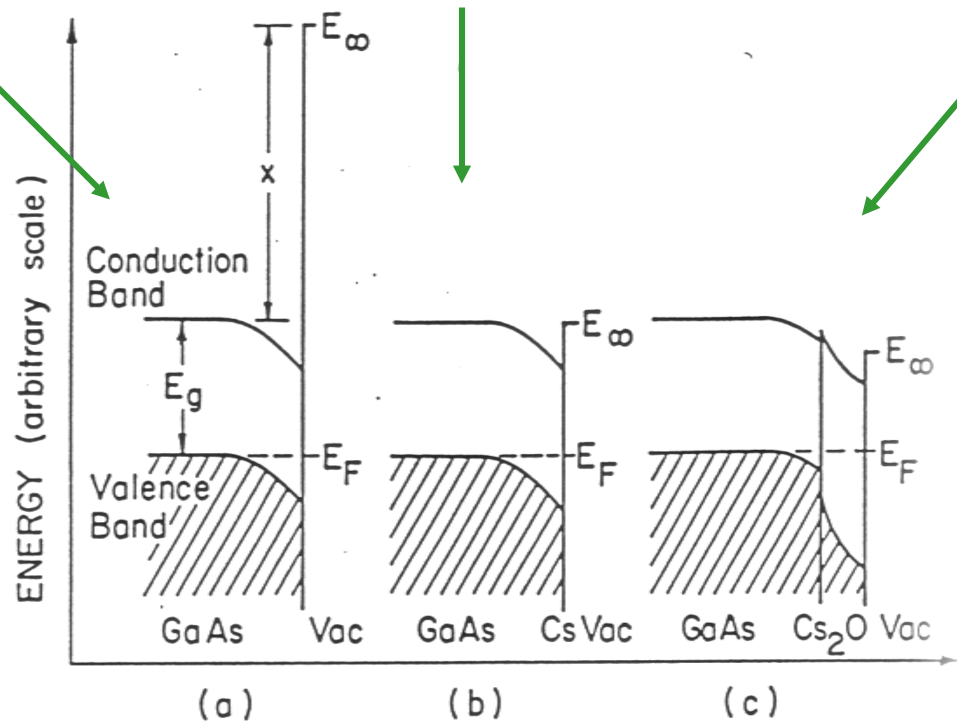


Photo-Emission from GaAs

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



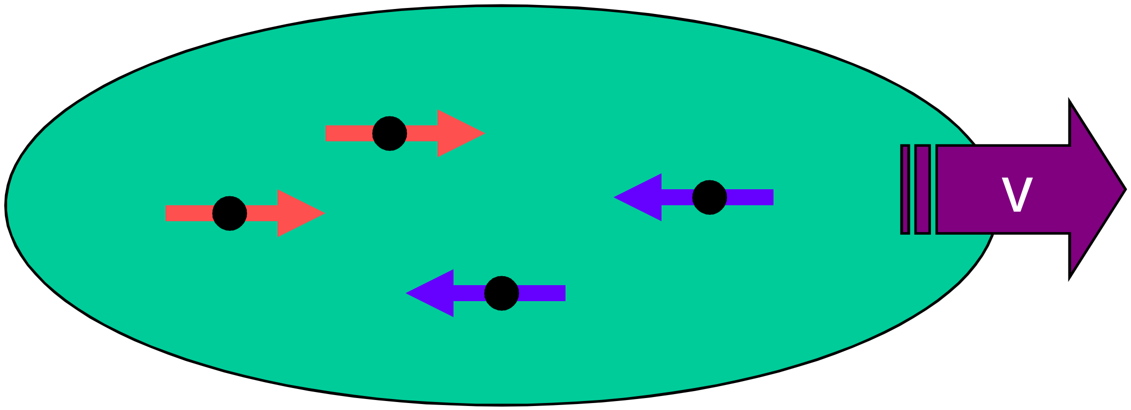
$$QE = \frac{\# \ e^- \text{'s}}{\# \ \gamma\text{'s}}$$

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

Electron Spin & Polarization

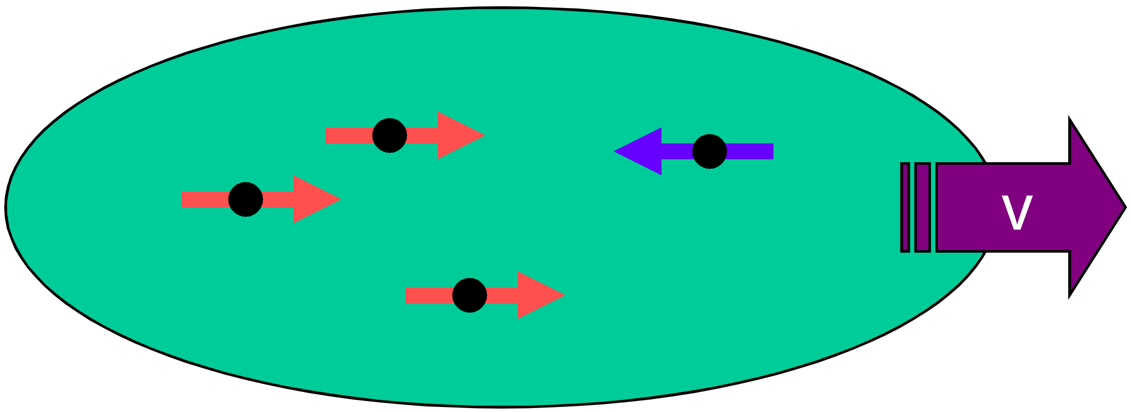
0% Polarization

L



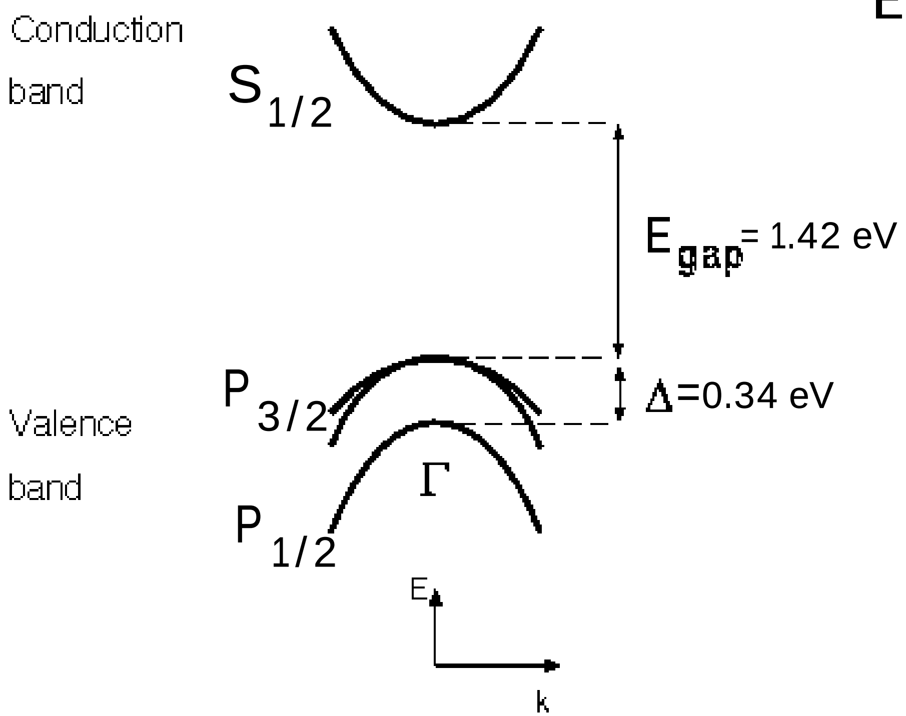
50% Polarization

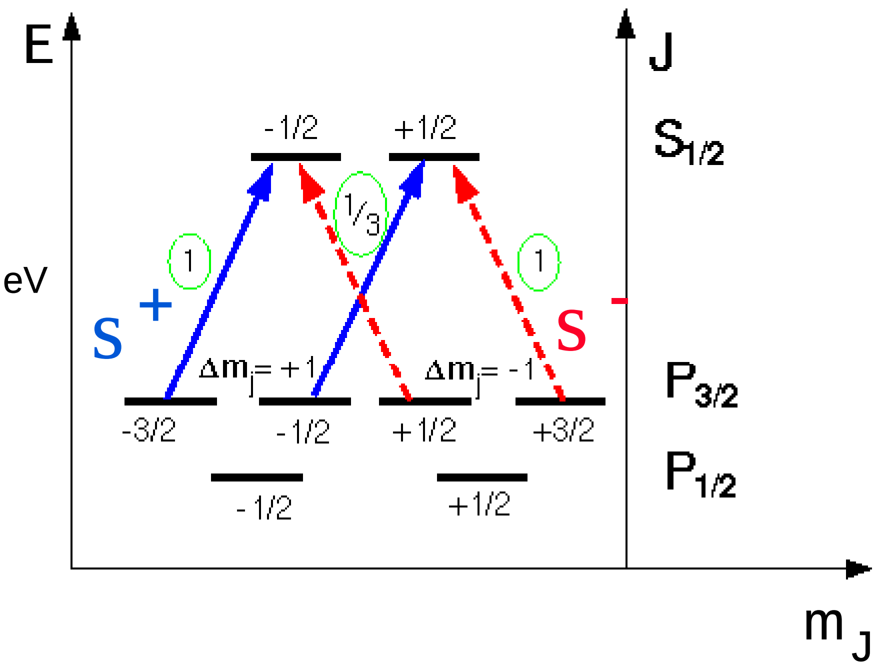
J



Aligning the Spin States in GaAs

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





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

hc / λ

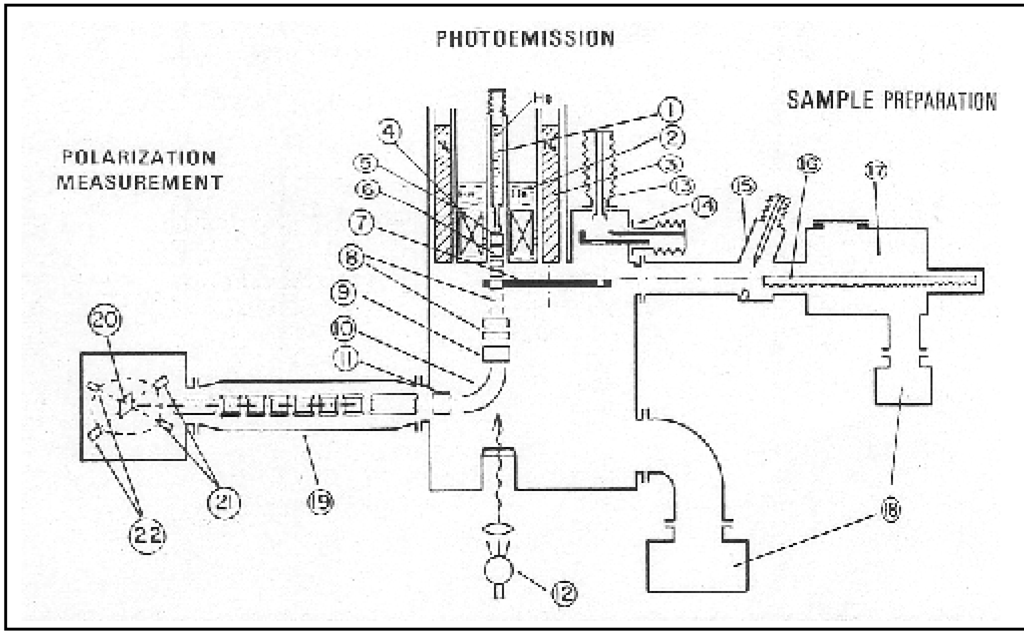
$$P_e = \frac{3-1}{3+1} = +/- \ 50\%$$

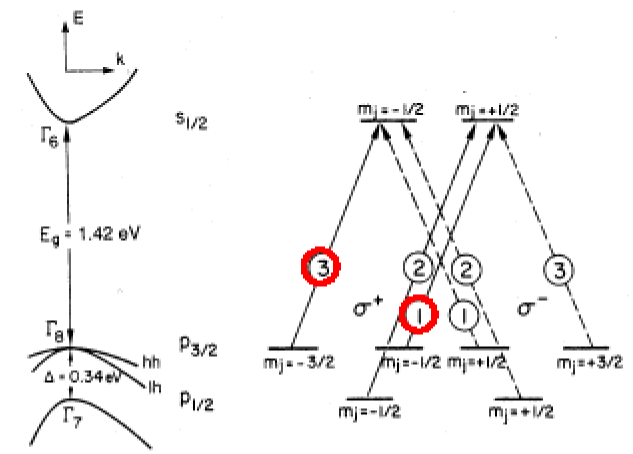
The First GaAs Photoemission Gun

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)





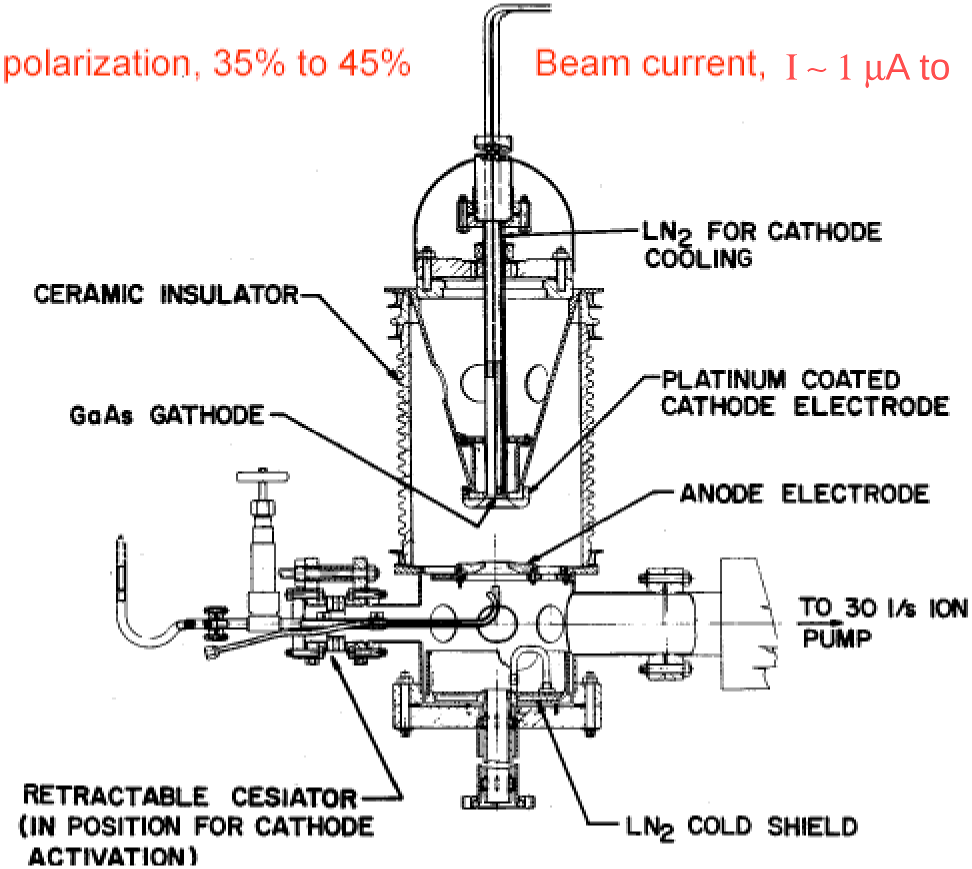
$$P = \frac{3-1}{3+1} = 50\%$$

First High Voltage GaAs Photogun

Polarized e⁻ Gun for SLAC Parity Violation Experiment

Beam polarization, 35% to 45%

Beam current, I ~ 1 μA to 15 A peak



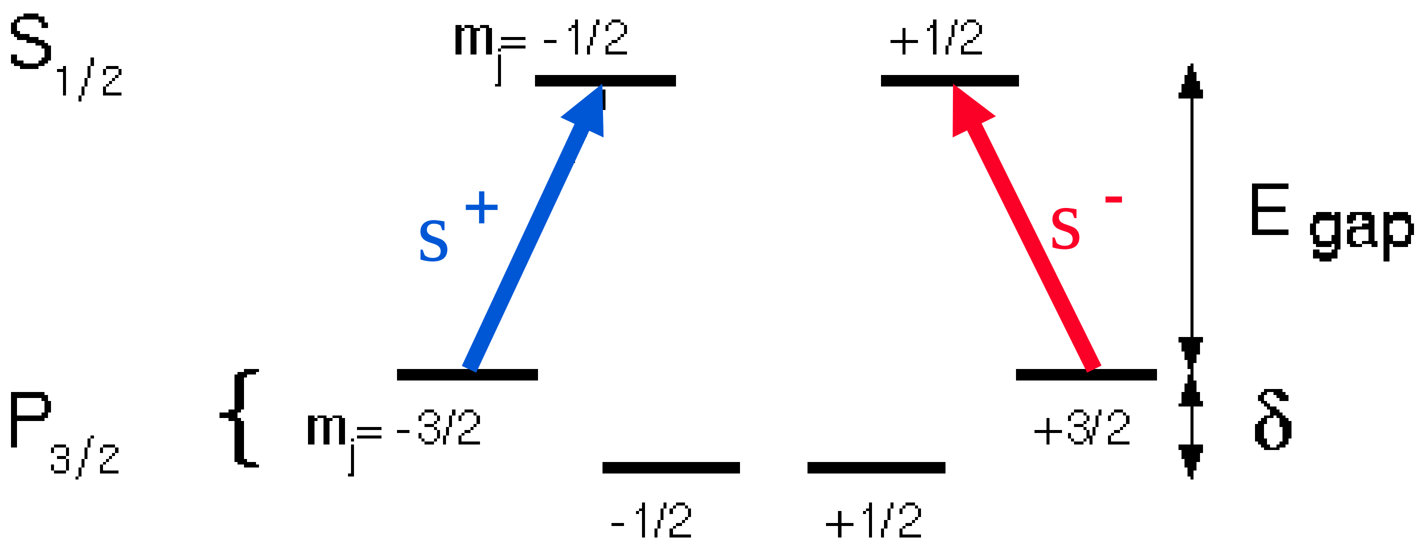
Electrons into the accelerator Dec., 1977

Collaboration announces parity violation June, 1978

Breaking the degeneracy …

Split degeneracy of $P_{3/2}$

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



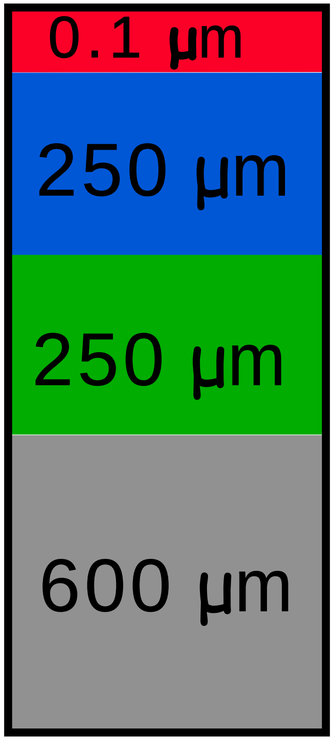
P_e = +/- 100%, with $E_{gap} < E_g < E_{gap+d}$

Strained layer GaAs

Bandwidth Semiconductor (formerly *SPIRE*)

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

  ⇒ split degeneracy of $P_{3/2}$



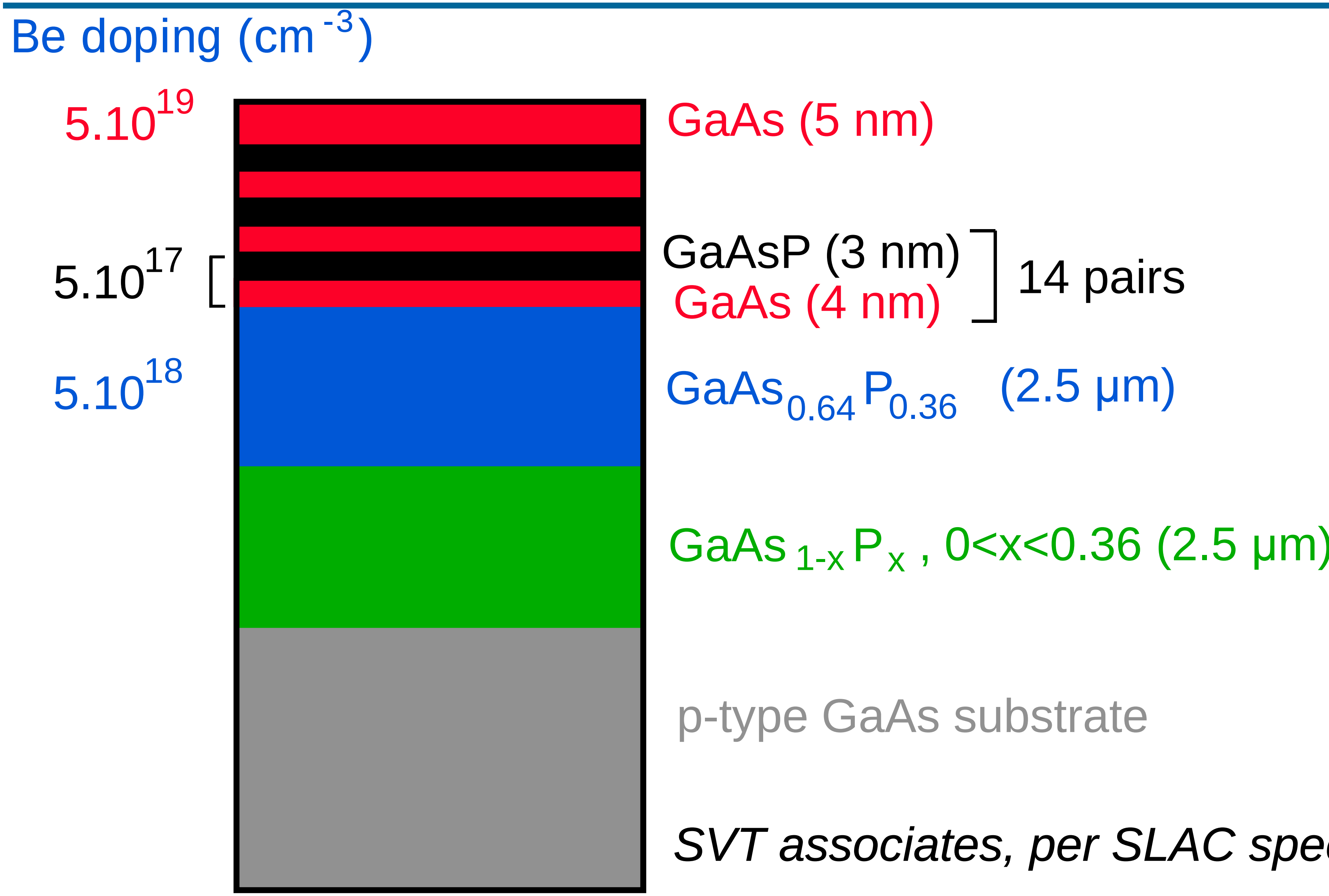
Strained GaAs

$GaAs_{1-x}P_x$ x=0.29

$GaAs_{1-x}P_x$ 0<x<0.29

p-type GaAs substrate

Strained Layer - Superlattice GaAs



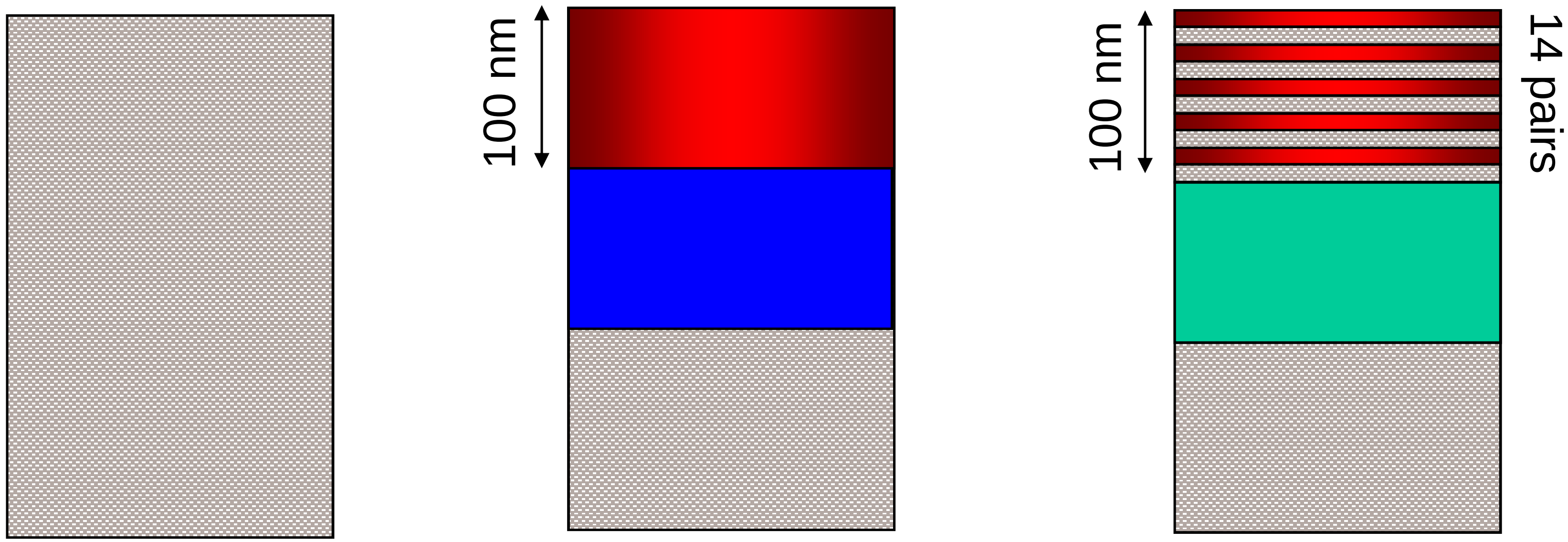
SVT associates, per SLAC specs.

Photocathode Material

Bulk GaAs

Strained GaAs:
GaAs on GaAsP

Superlattice GaAs:
Layers of GaAs on GaAsP



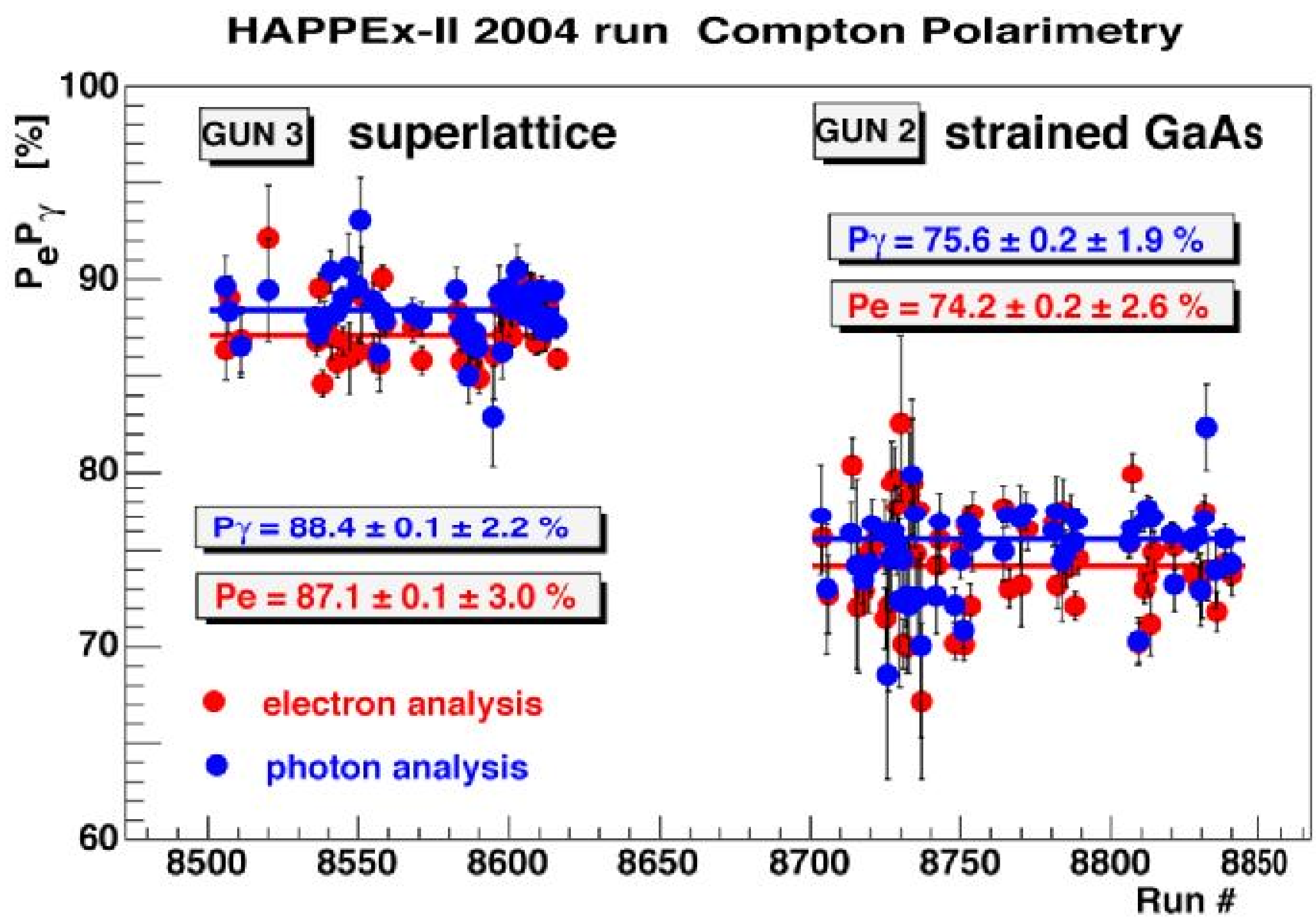
High QE ~ 20%
Pol ~ 35%

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

No strain relaxation
QE ~ 1.0 %
Pol ~ 85%
@ 780 nm

$$\mathrm{FOM}\ \mu\ I\ P^2$$

And, it really works!



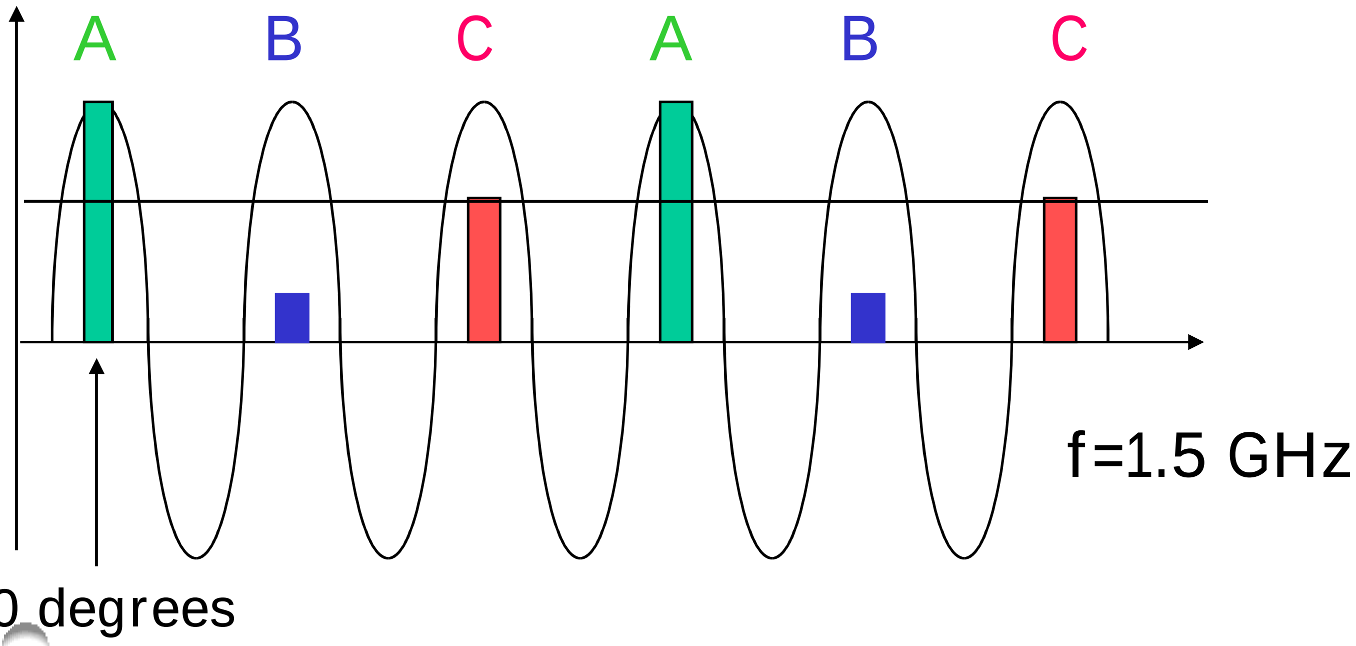
Experiment Figure of Merit

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

CEBAF Overview

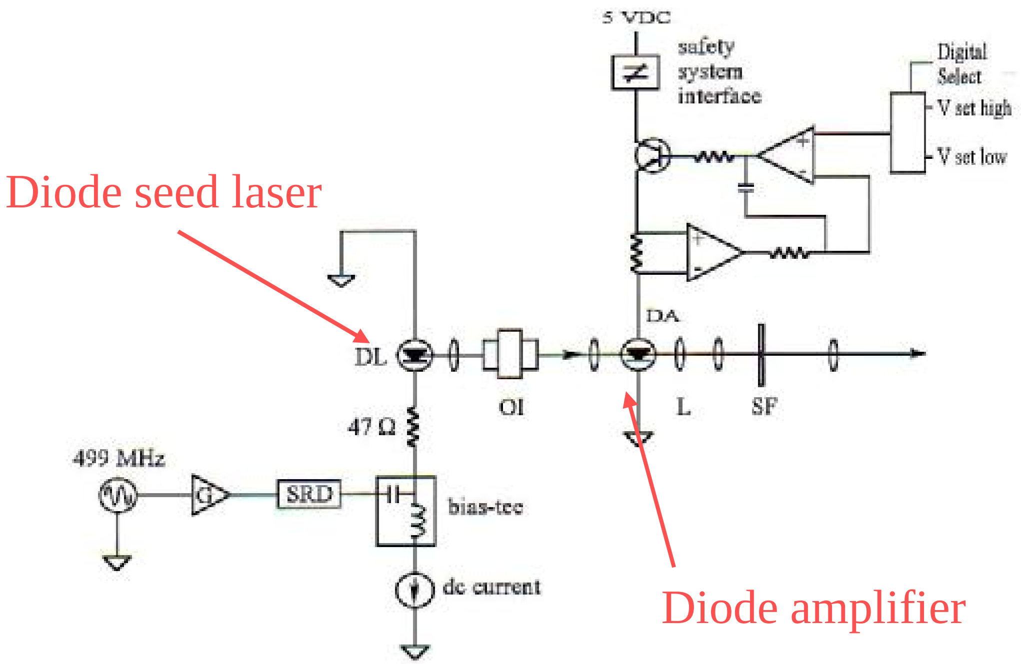
CEBAF Benefits;

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

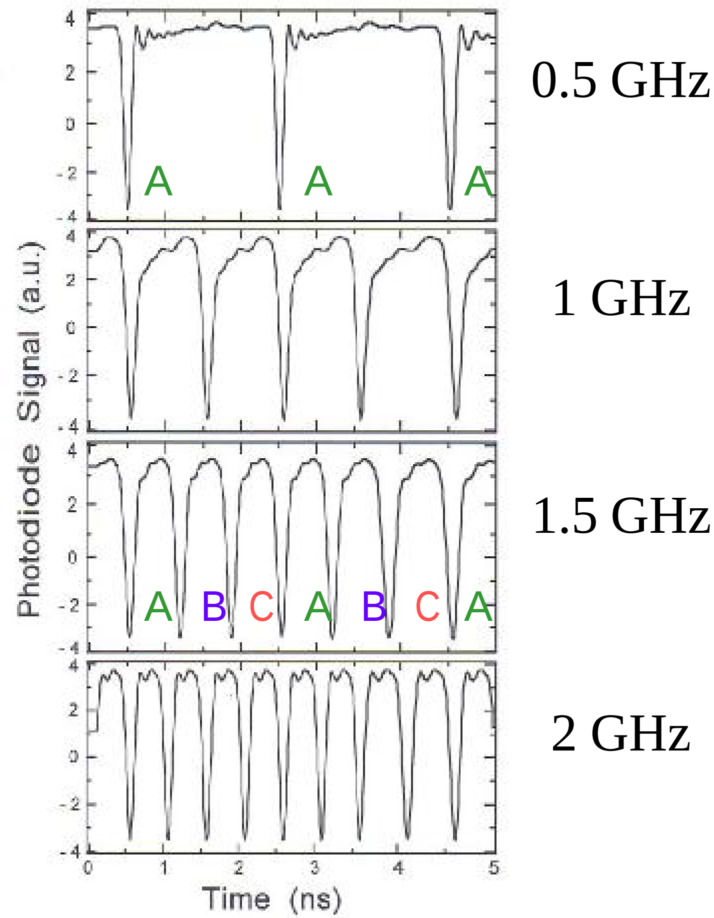


Radio Frequency Pulsed Lasers

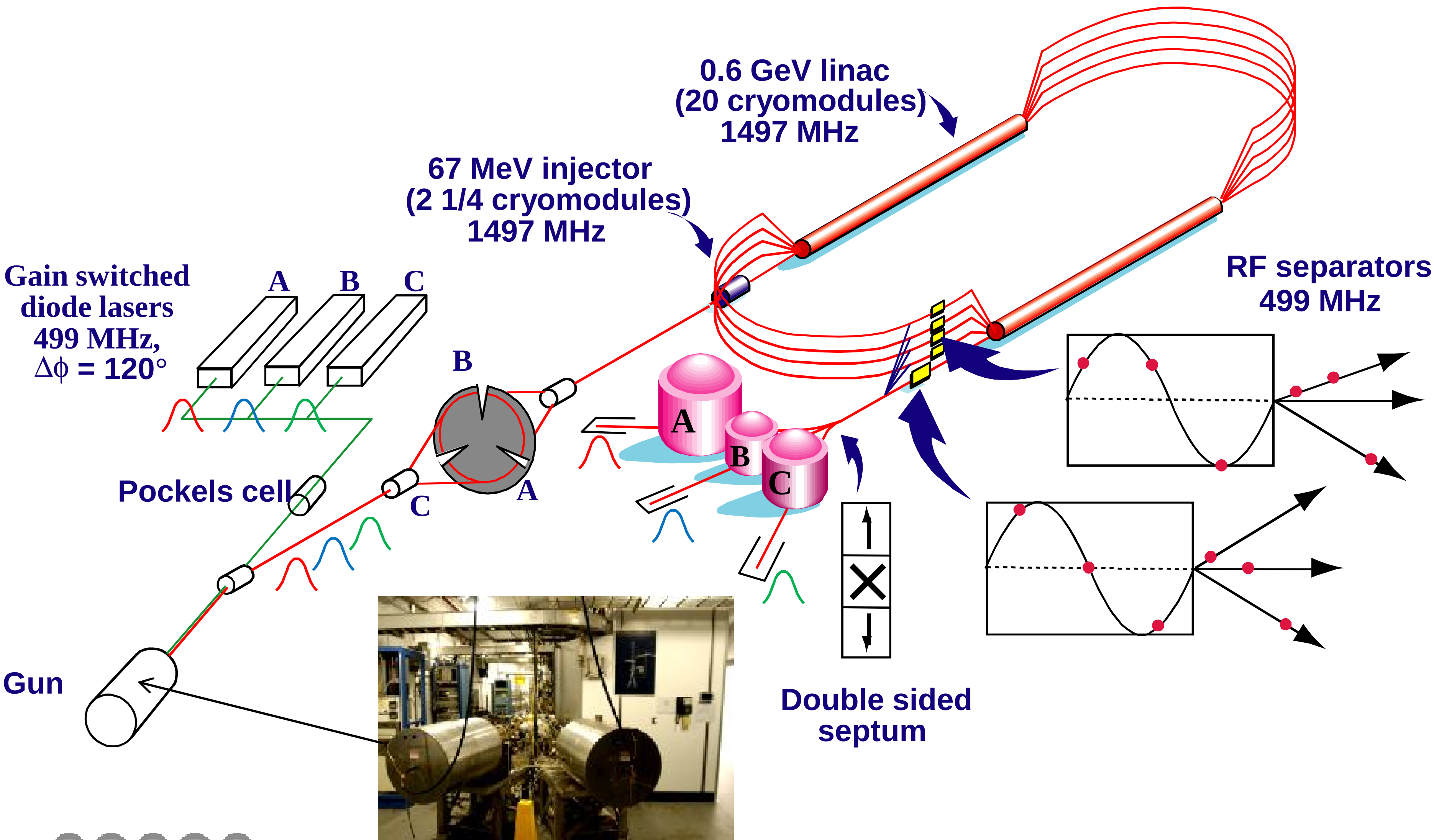
RF Gain Switching



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

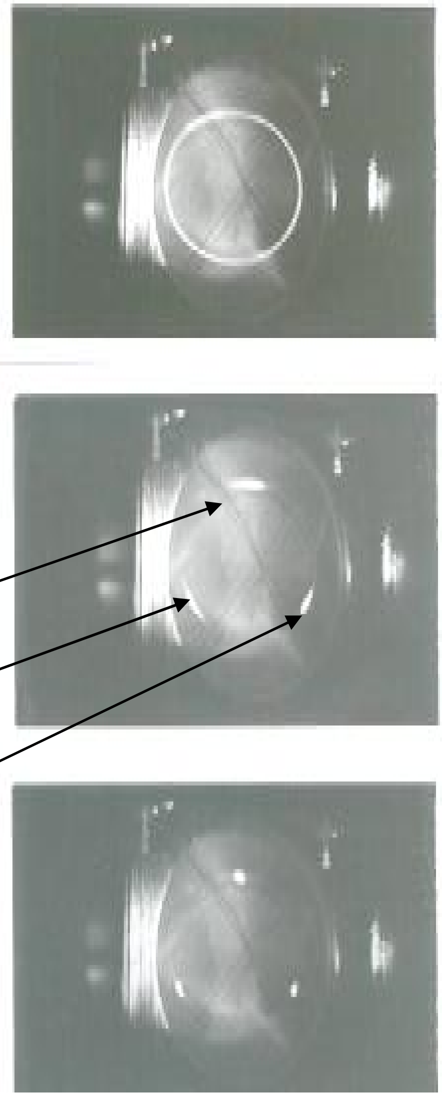


Continuous Electron Beam Accelerator Facility



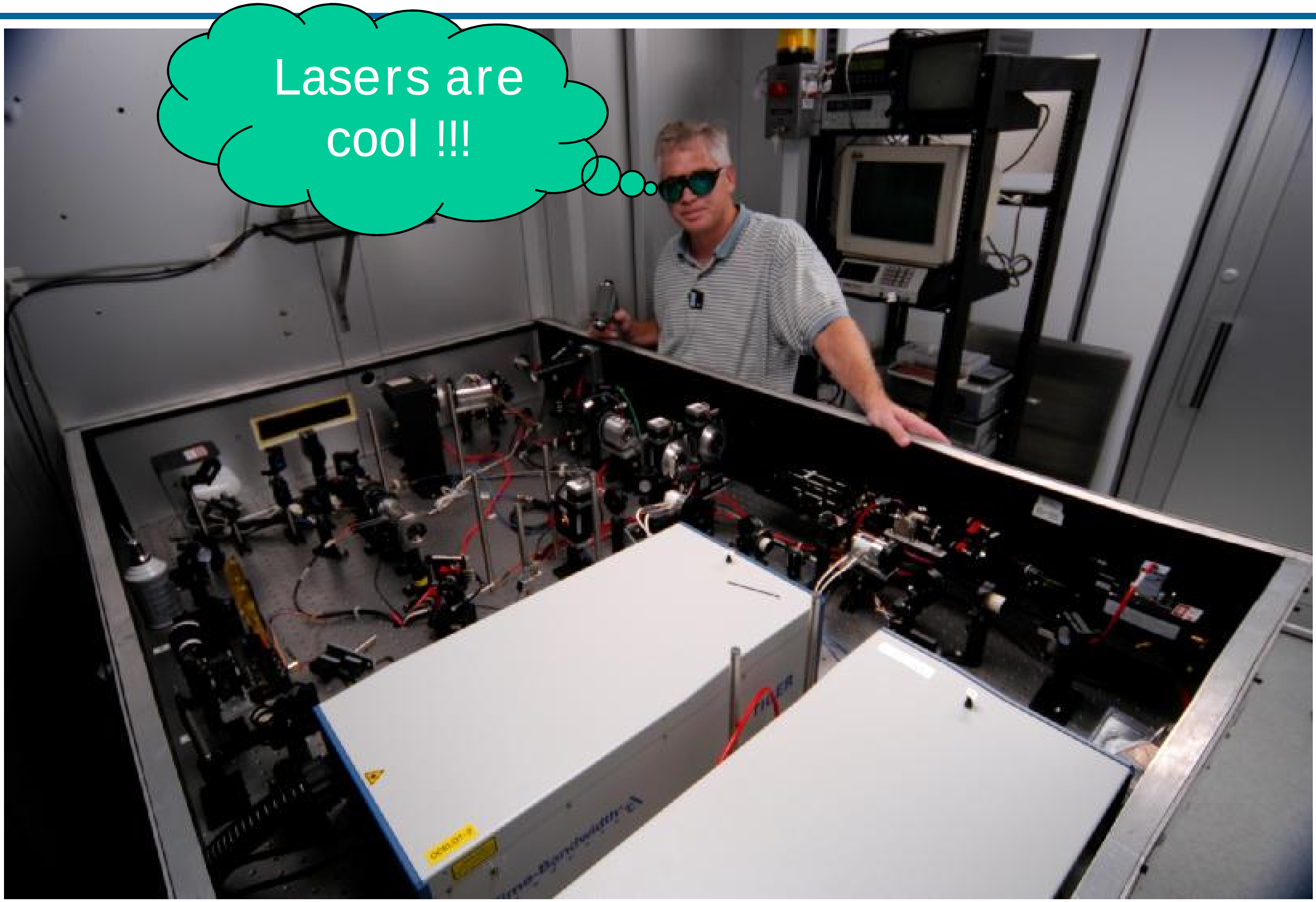
Synchronous Photoinjection

Chopper viewer for three beams;

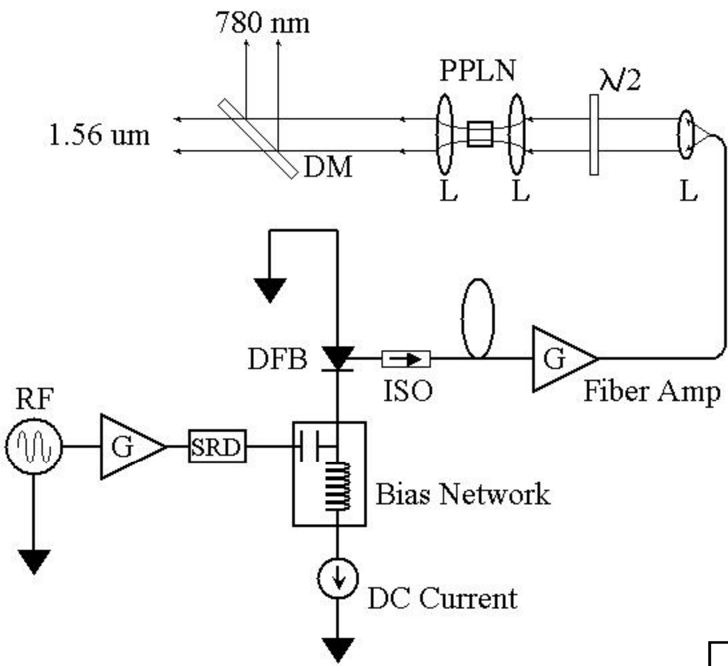


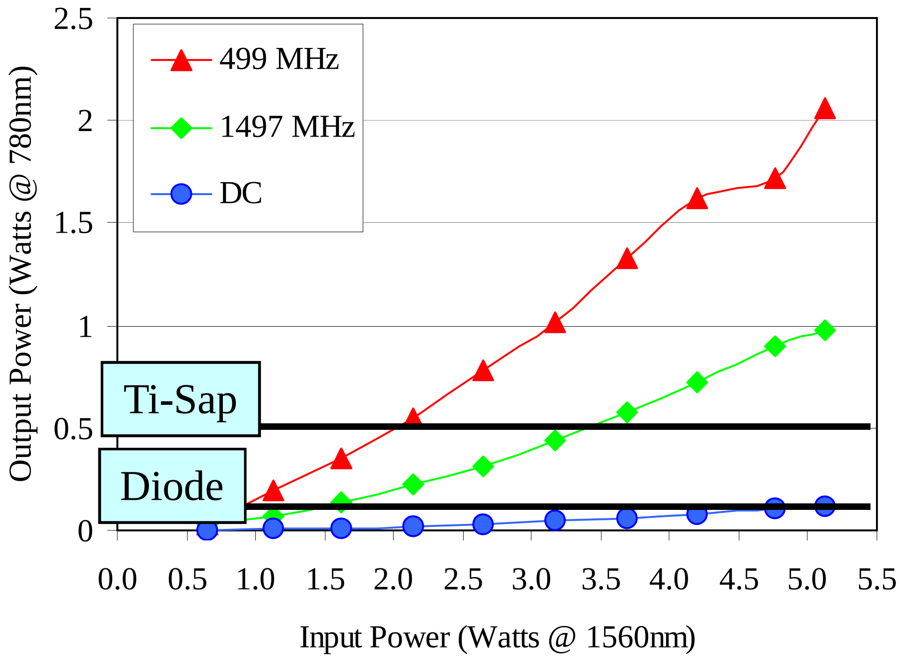
- DC Laser (wasted electrons)
- Pulsed laser (much better)
- PreBuncher (even better)

Laser Room for Dust & Climate Control



New Fiber-Based Drive Laser





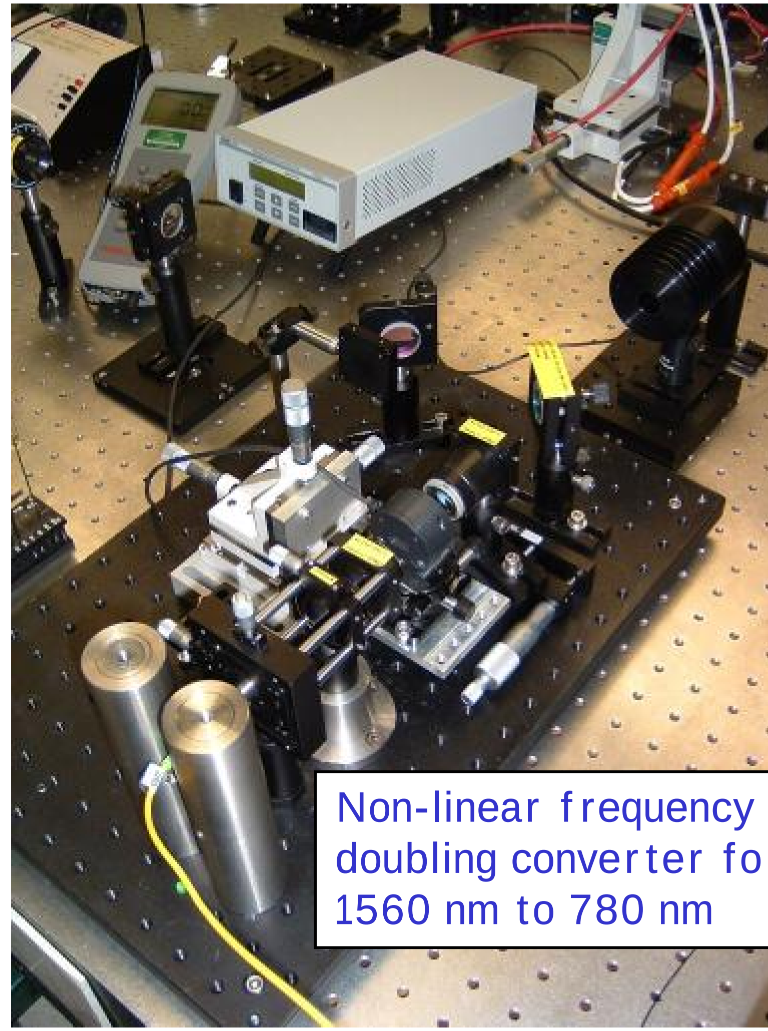
J. Hansknecht and M. Poelker, Phys. Rev. ST Accel. Beams 9, 063501 (2006)

- 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)

New fiber technology-based laser system

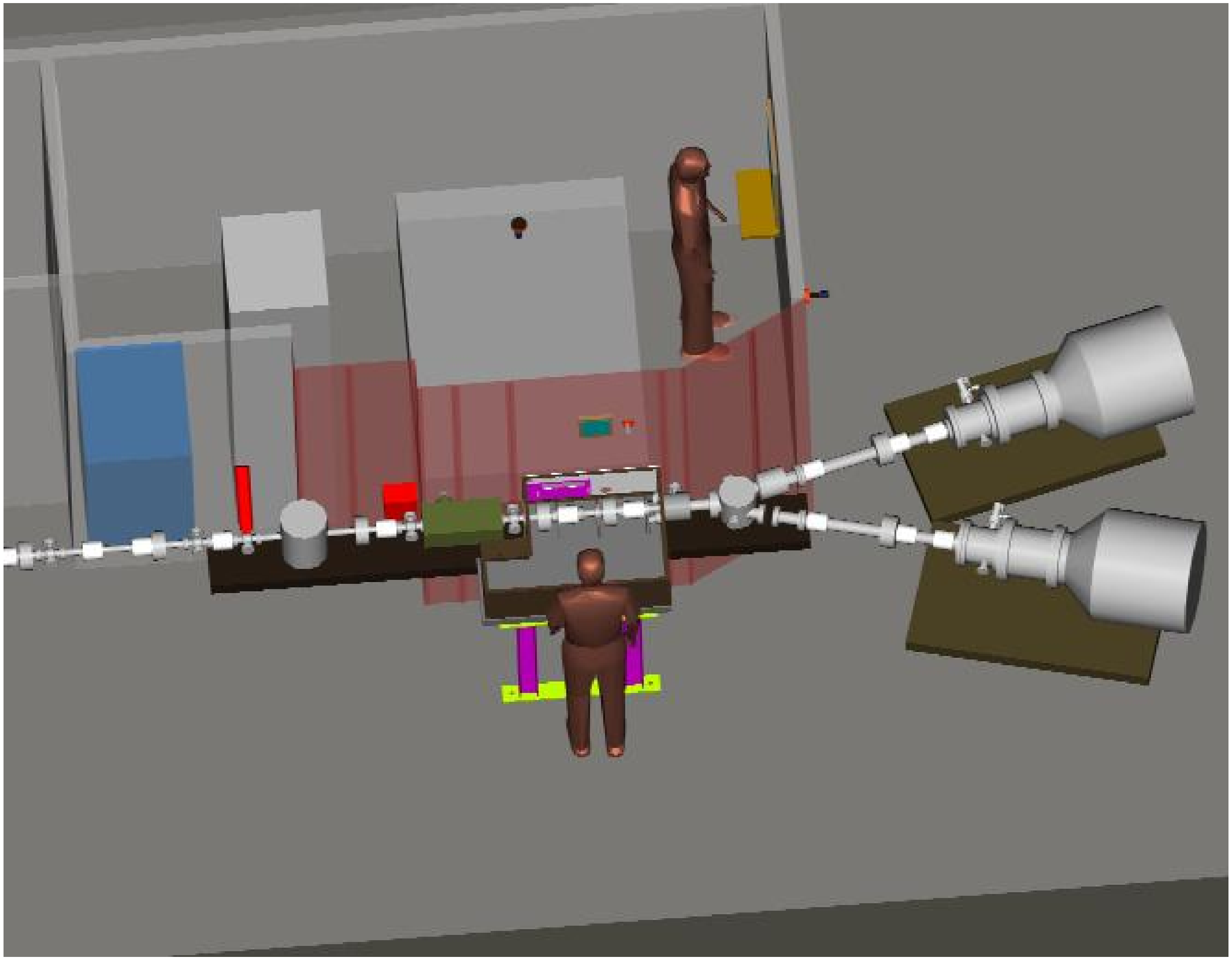
RF locked low-power 1560 nm fiber diode

High power 1560 nm fiber amplifier

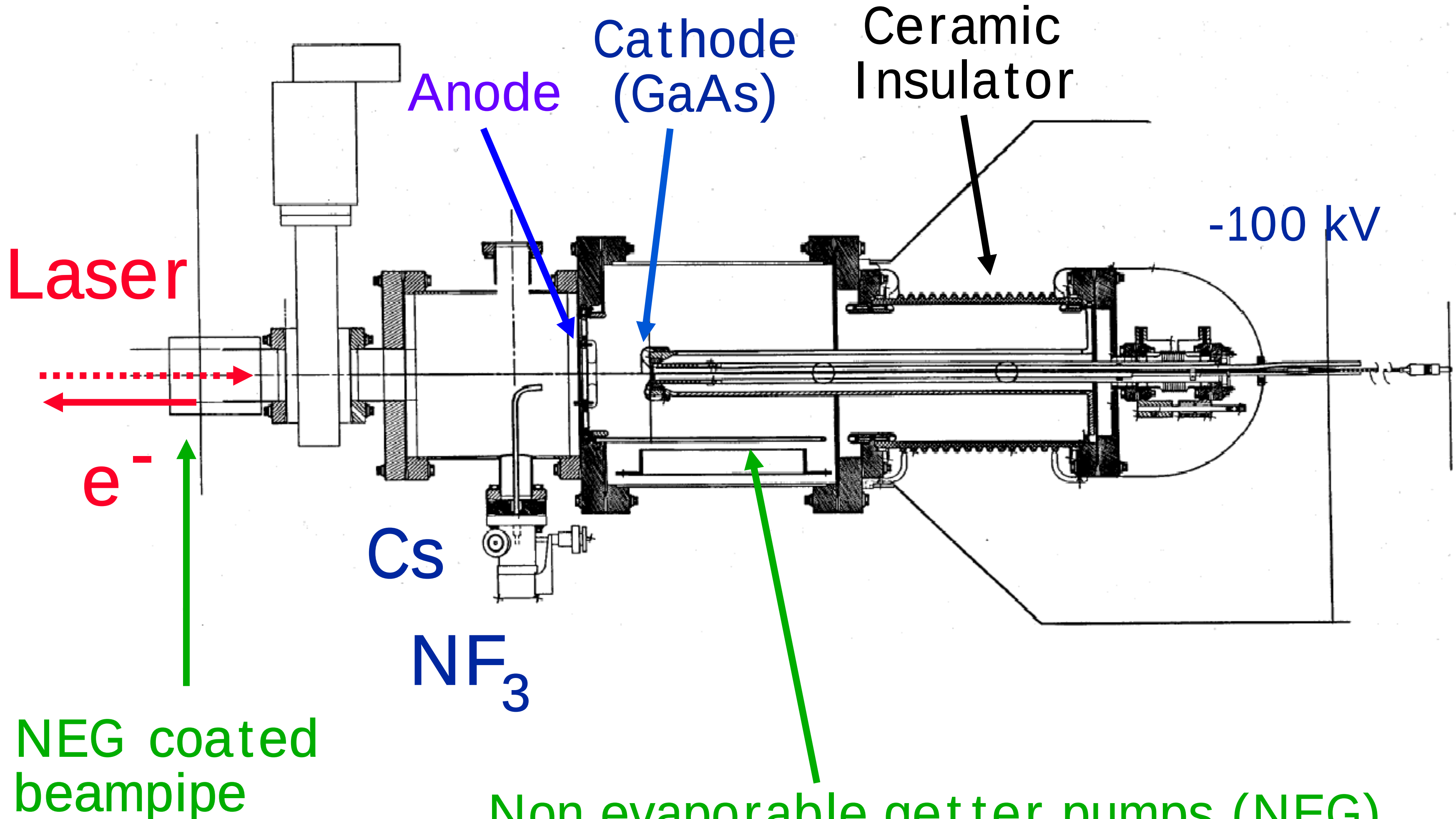


Non-linear frequency doubling converter for 1560 nm to 780 nm

"100 keV" Photoinjector

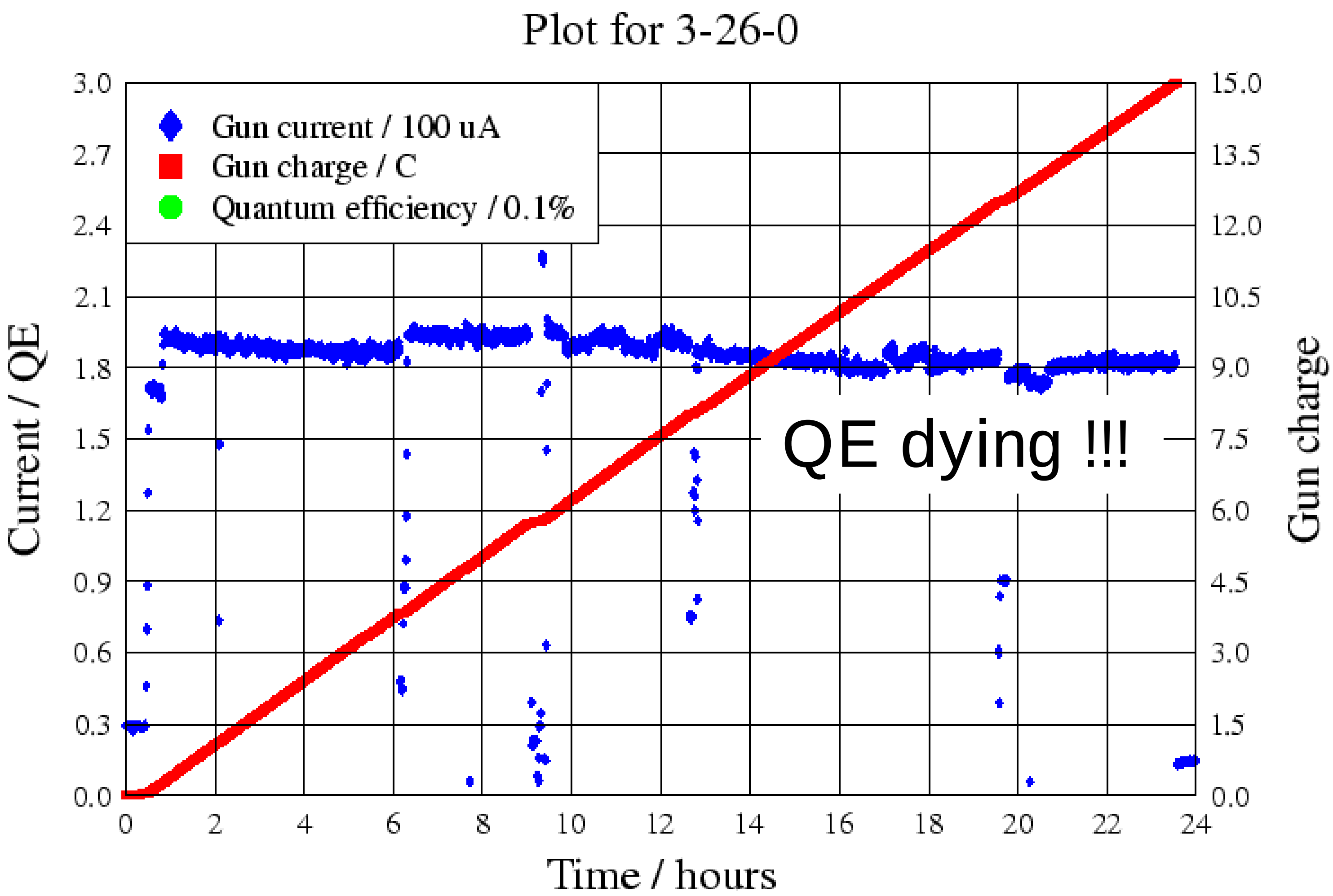


JLab vent/bake polarized source…



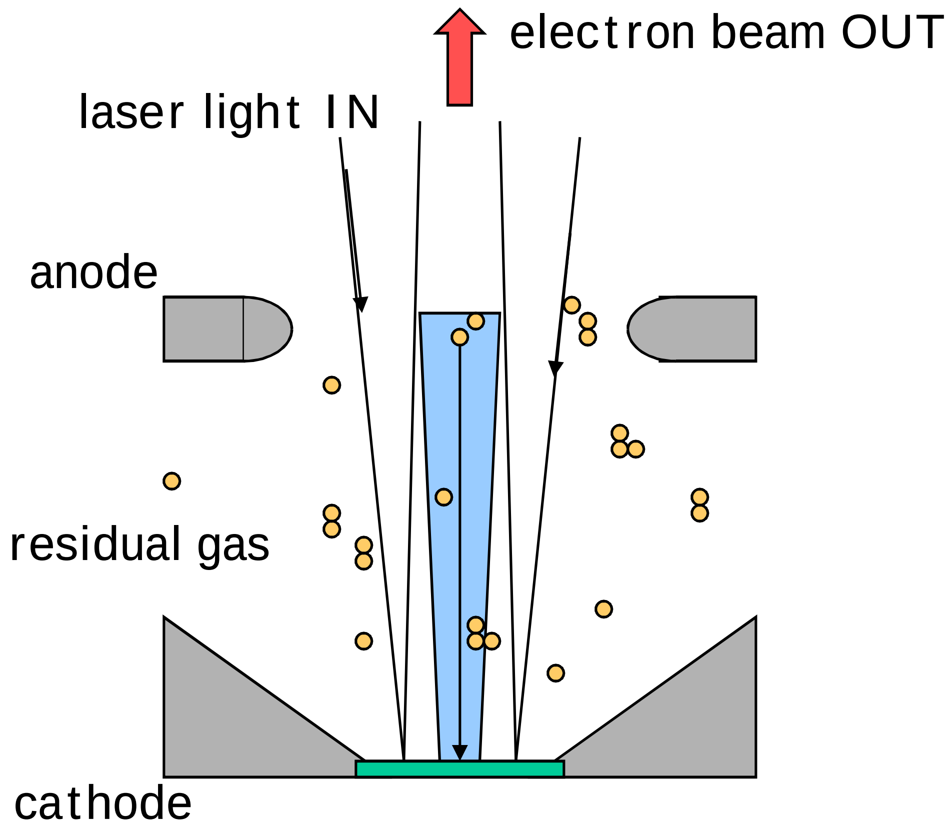
4,000 liter/s pump speed ⇒ 5E-12 Torr

Who wants polarized electrons?

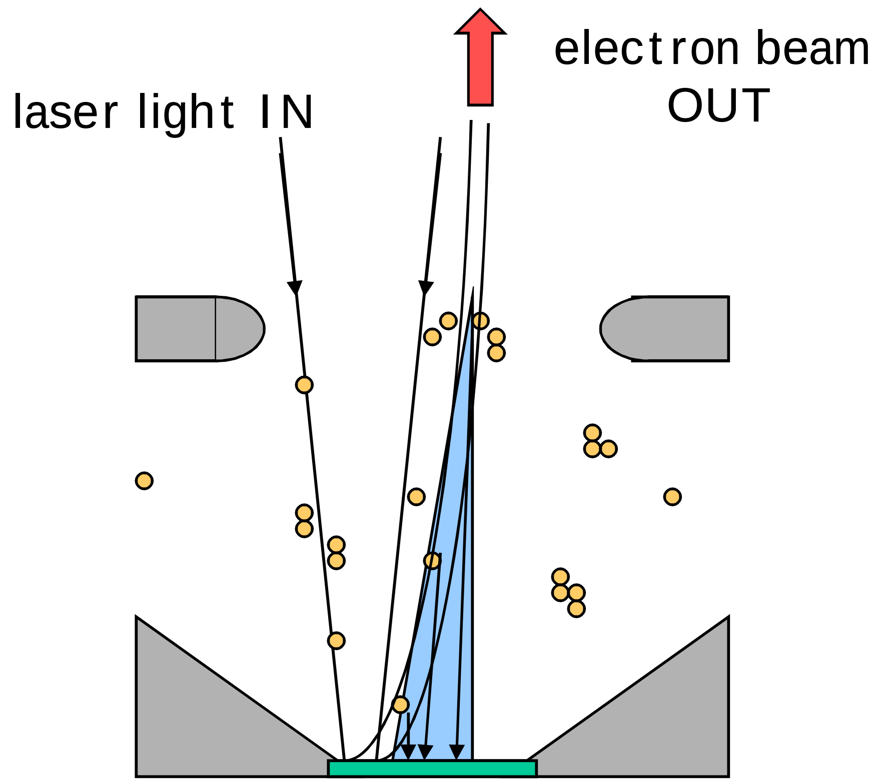


Ion Back-Bombardment

High energy ions focused to electrostatic center



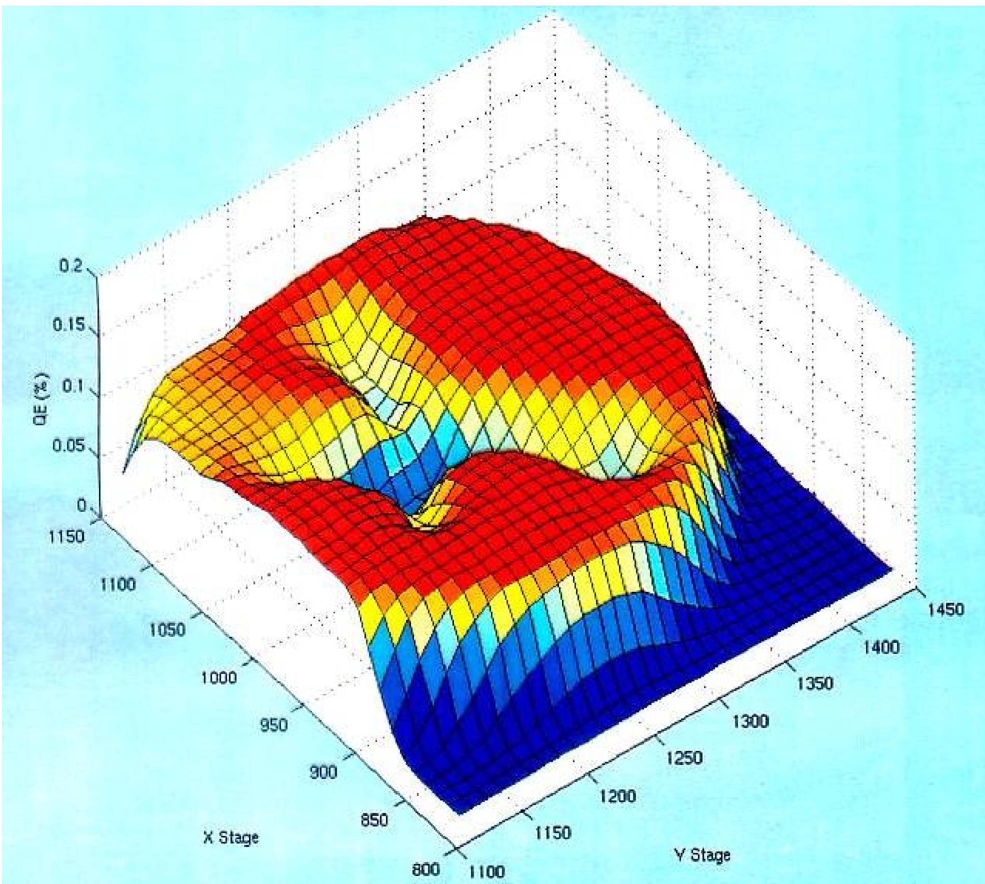
We don't run beam from electrostatic center

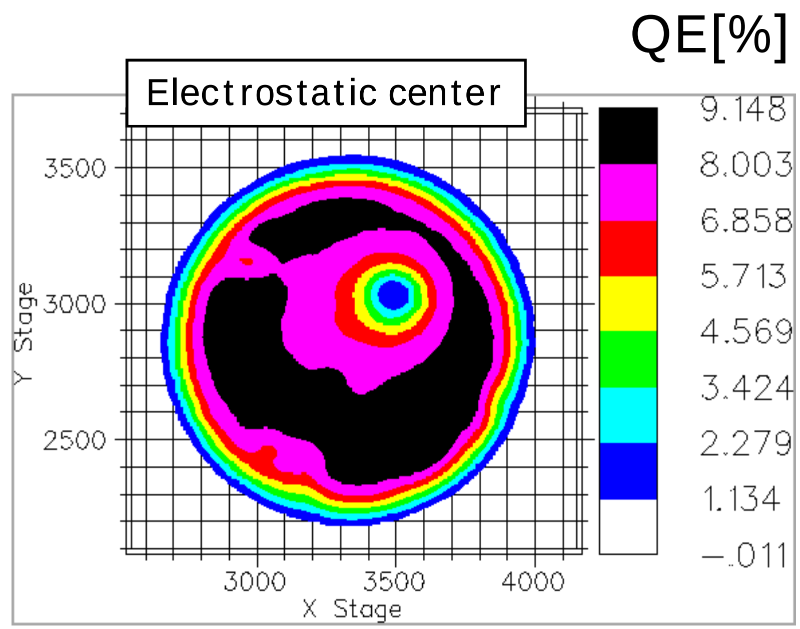


Ions create QE trough to electrostatic center

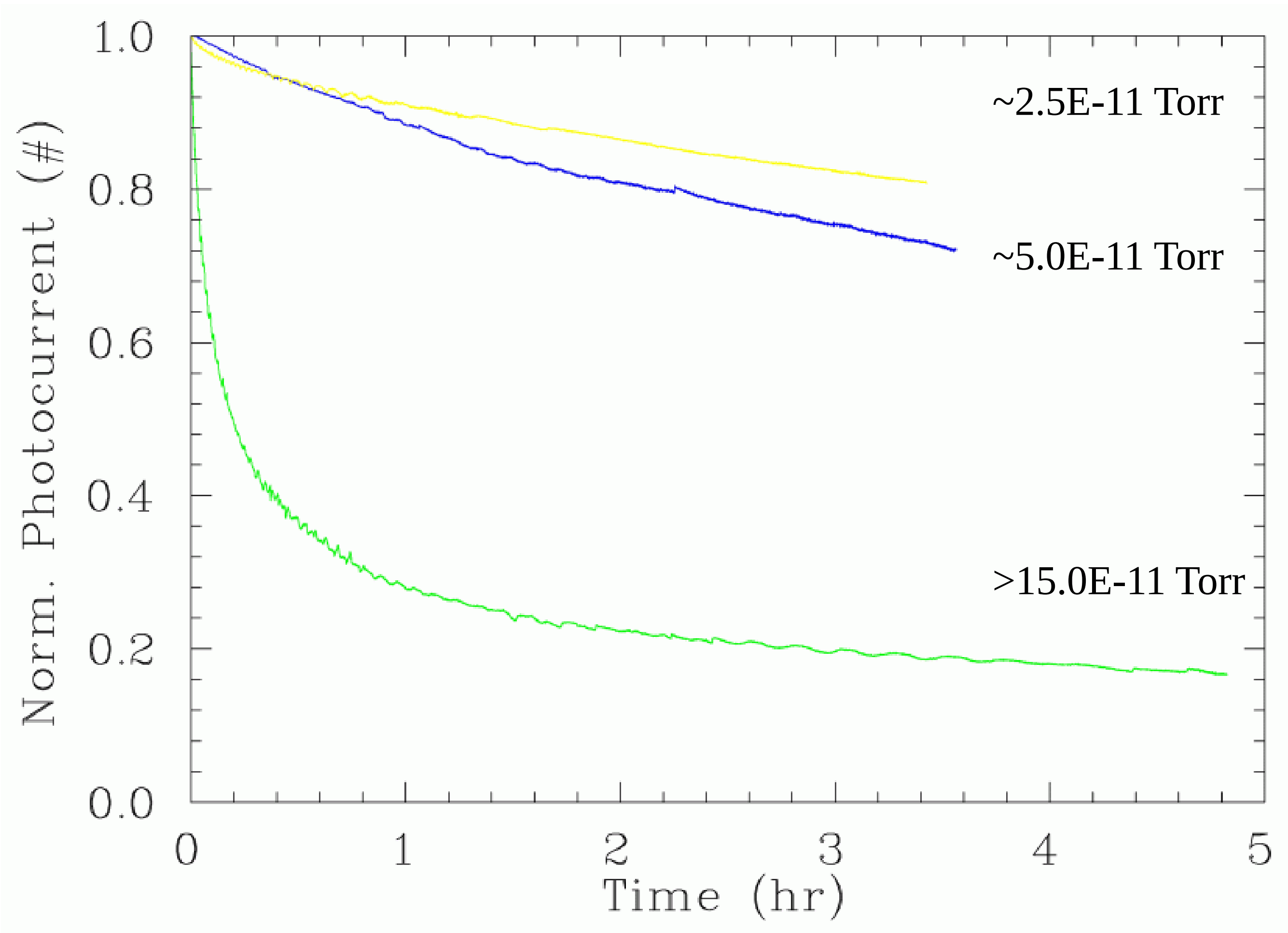
Bad, bad ions...

Imperfect vacuum => QE degrades via ion backbombardment





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

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/Extreme high vacuum
SRF cavity vacuum	< 10^{-12} Torr	Inside SRF cavities with walls at 2K	Extreme high 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

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.
- **Engineered 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

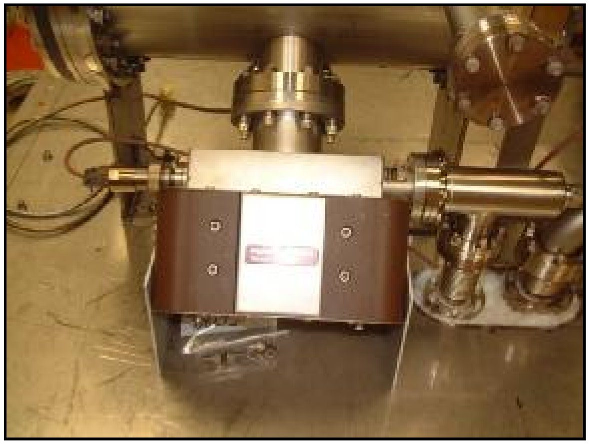
- **Getter Pumps**
  - Chemically active surface
    - Titanium sublimed from hot filament
    - Non-Evaporative Getters
  - Molecules stick when they hit
    - Does not work well for inert gasses such as Argon, Helium or for methane

- **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

- Avoid contamination by oils due to roughing pumps, fingerprints, machining residue.

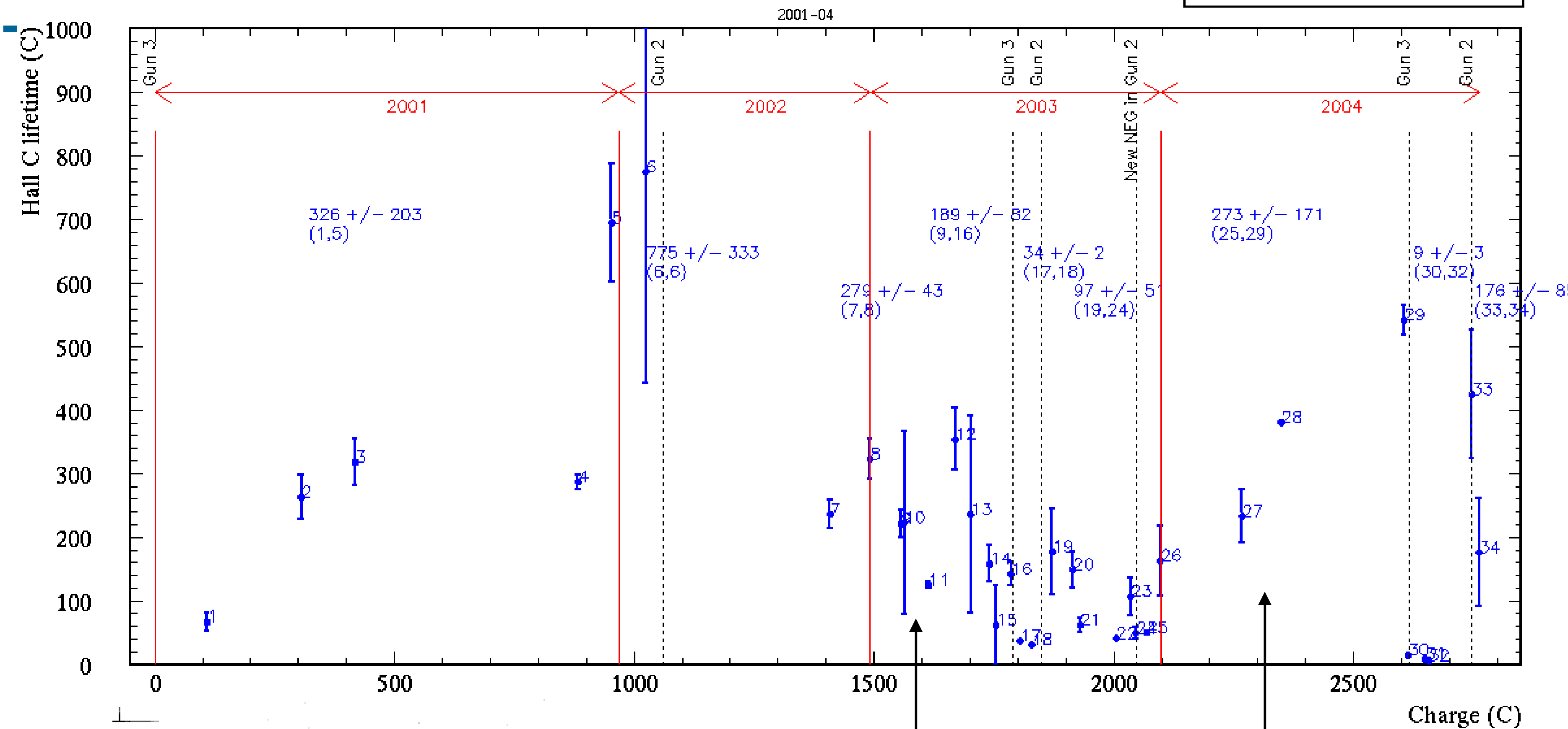
NEG pump array

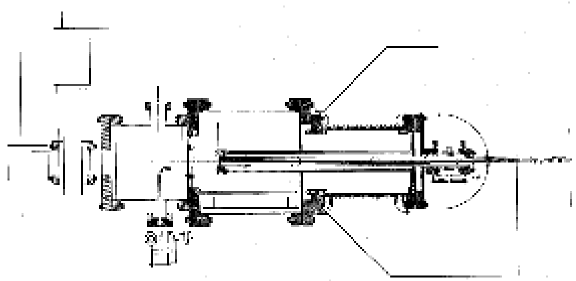


Ion Pump

CEBAF Gun Charge Lifetime (2001-2004)

Data compiled by M. Baylac



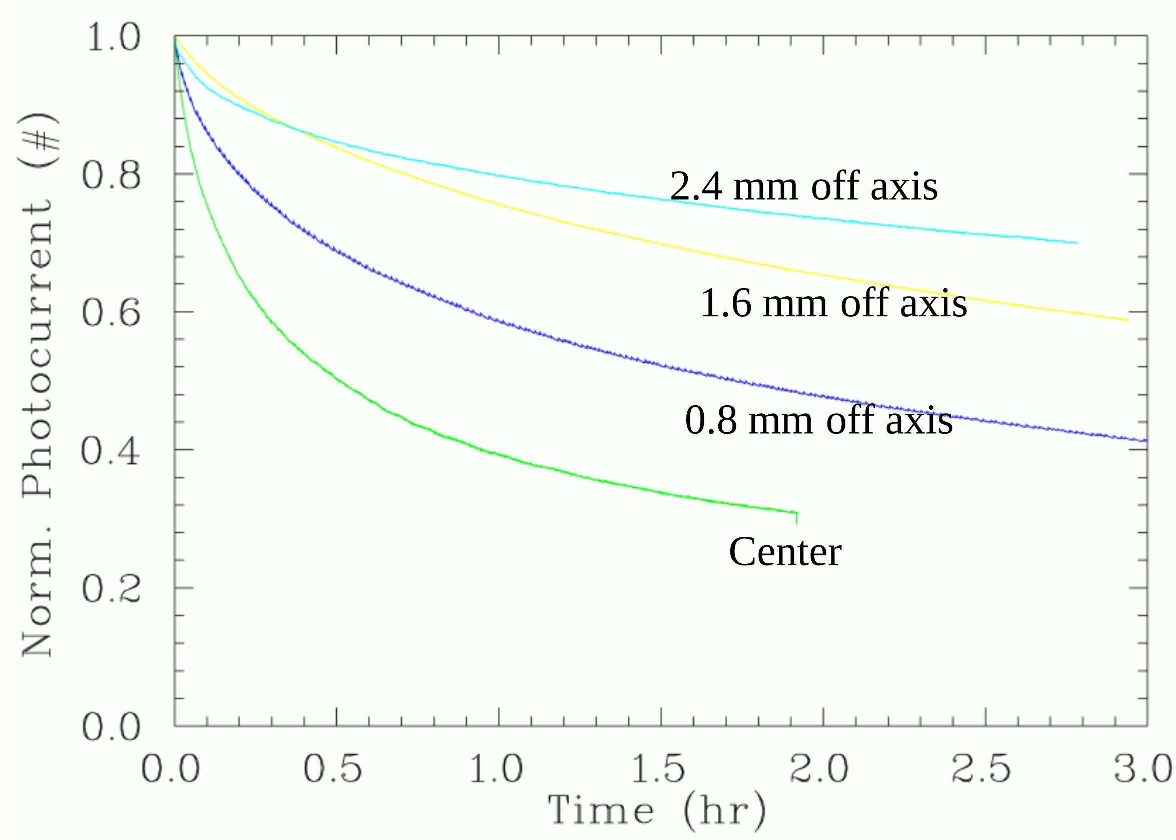


Charge Lifetime Steadily Decreasing

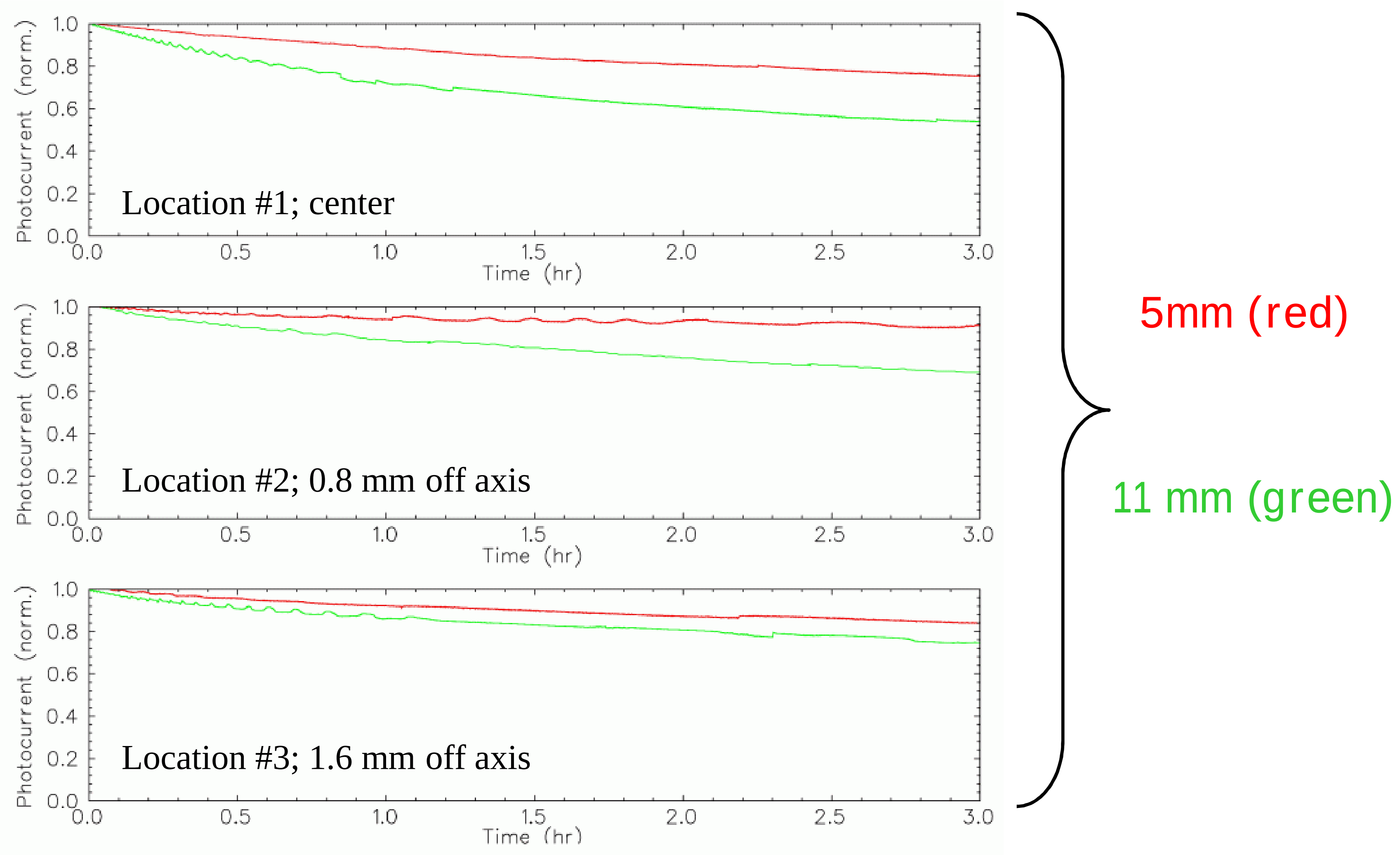
NEG replacement Summer 2003 improves lifetime

Lifetime vs. Beam Location

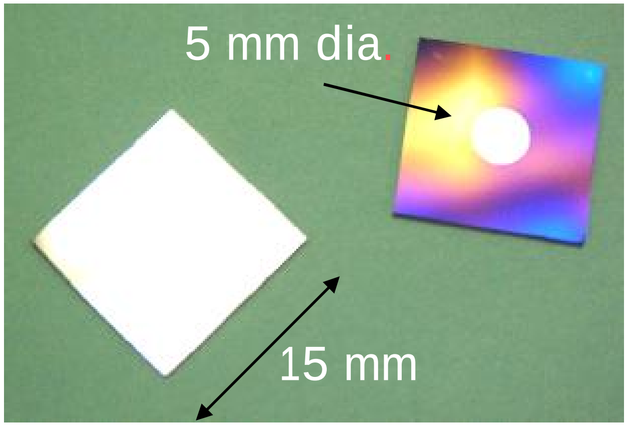
Ionized gas is attracted toward the electrostatic center of photocathode
Solution => position laser spot (e- beam location) off axis



Exposed Active Area



Limiting Active Area



Photocathode “out of box”

Anodize photocathode in electrolytic bath of weak phosporic acid.

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.

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)

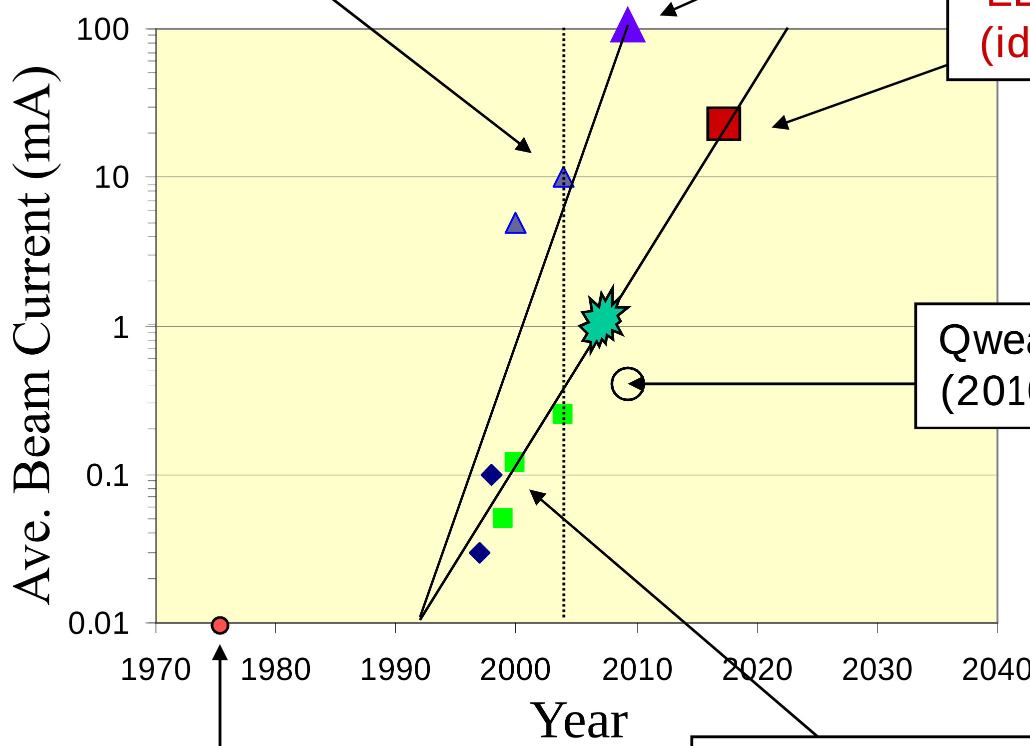
What now … ???

GaAs Trending Higher Average Current

JLab FEL program with unpolarized beam

Cornell/JLab (construction)

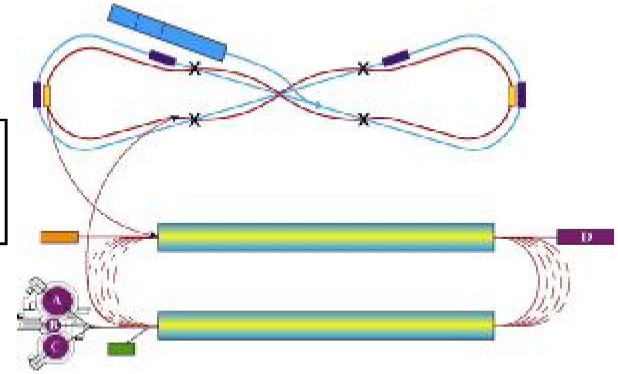
ELIC (idea)

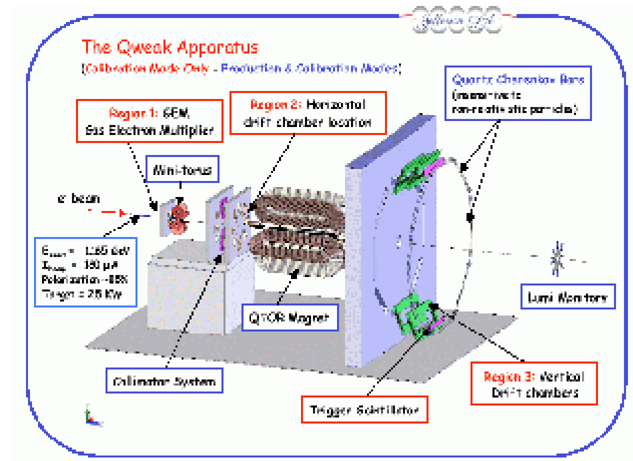


Qweak (2010)

First polarized beam from GaAs photogun

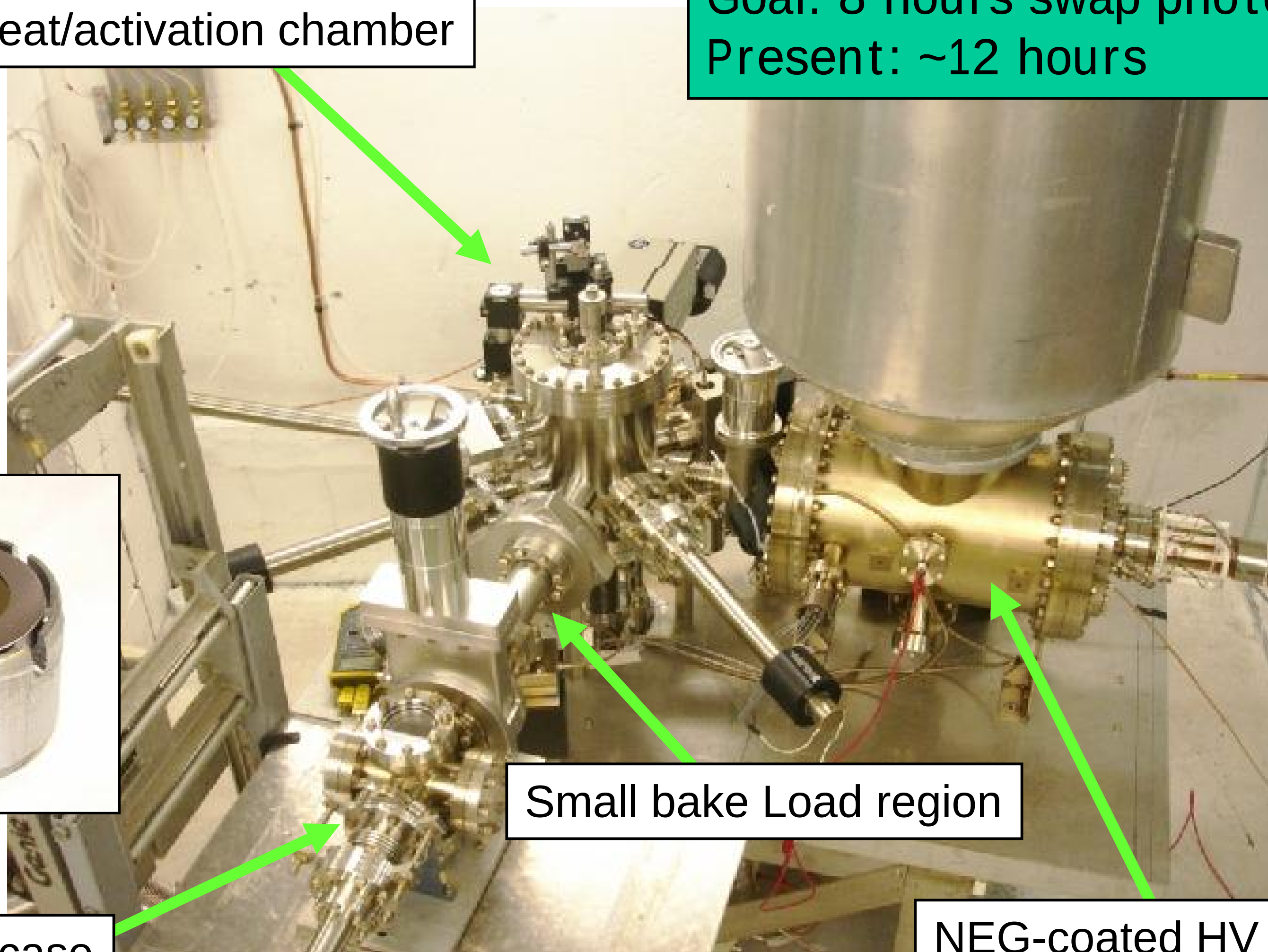
First low polarization, then high polarization at CEBAF





New Load Lock Gun in Test Stand Spring ‘06

Goal: 8 hours swap photocathode
Present: ~12 hours



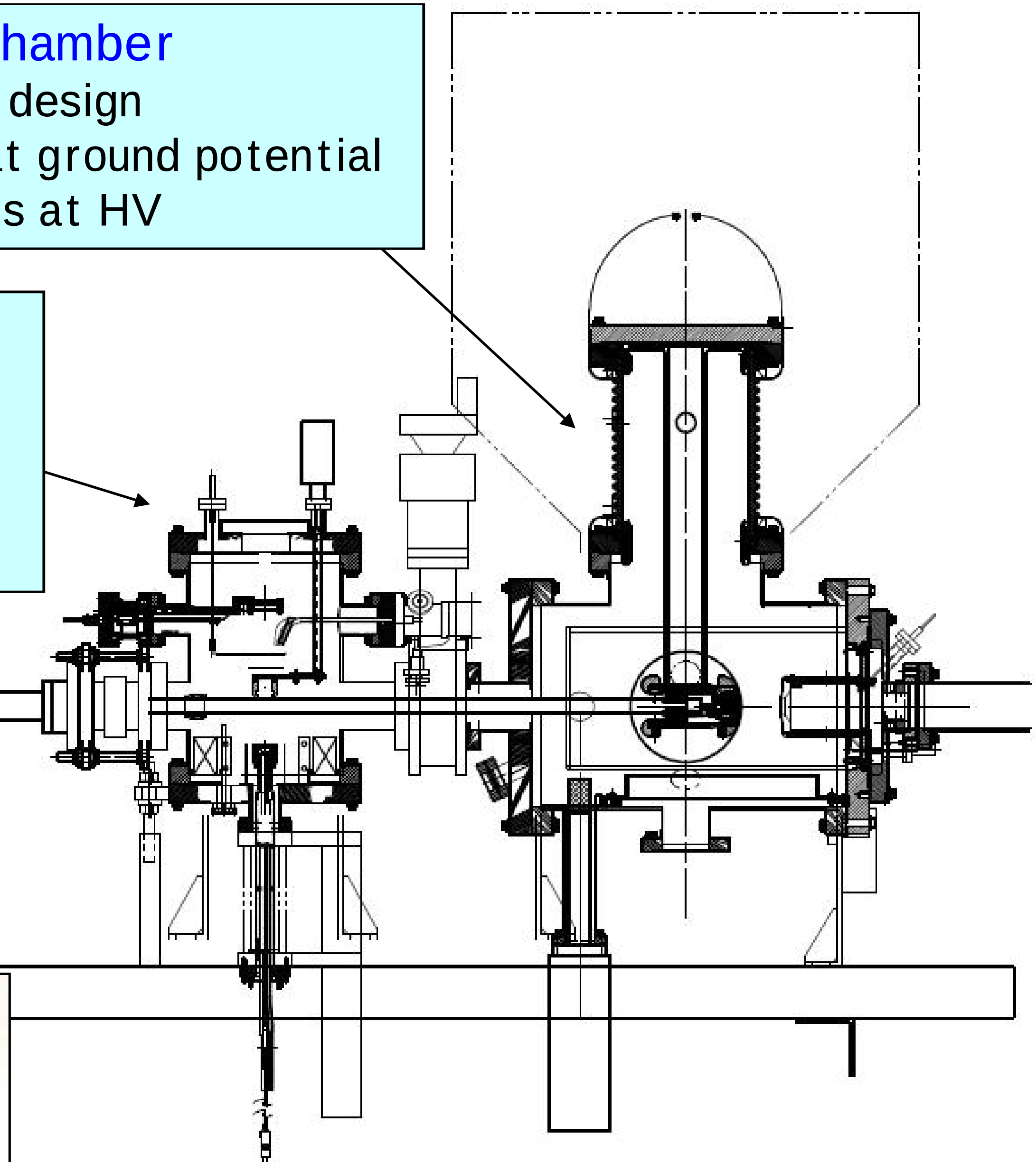
x4

High Voltage Chamber

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

Activation Chamber

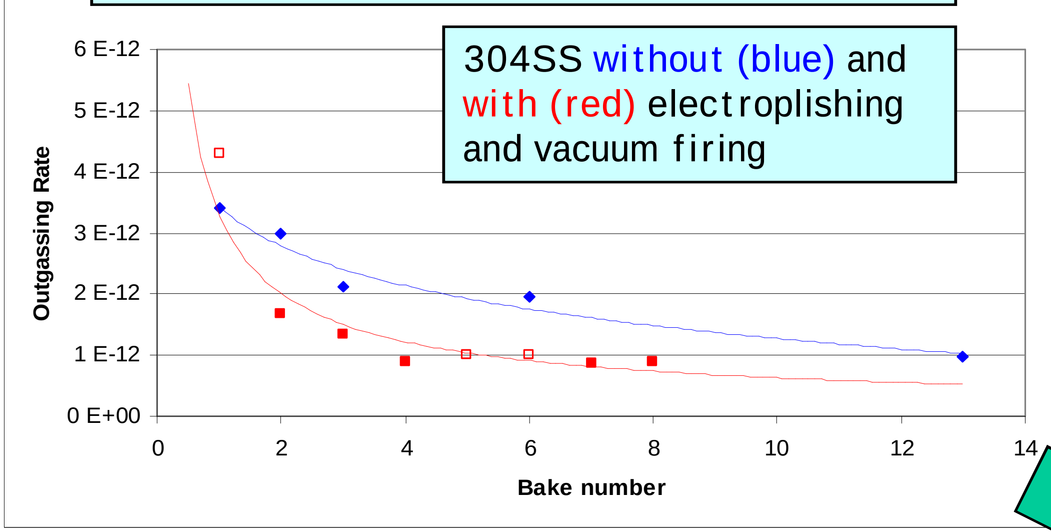
- Mini-stalk heater
- Mask selects active area
- UHV IP supplies gauge activation
- Keyed & eared pucks



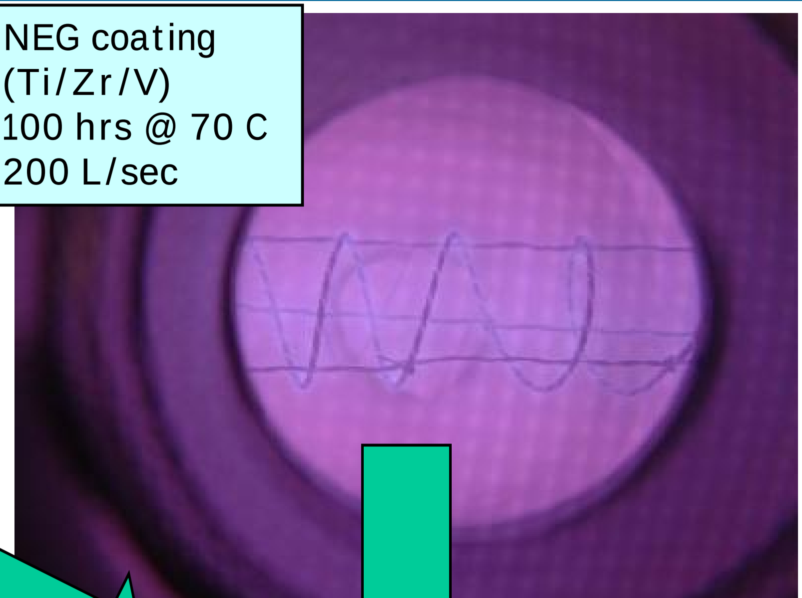
Improvements to the High Voltage Chamber Vacuum

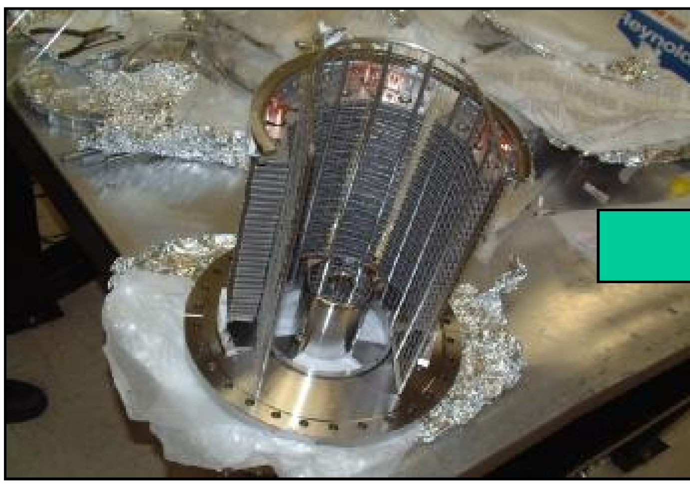
304 SS: Electropolished & Vacuum Fired
(AVS: 3 hrs @ 900 C @ 3x10^{-6} T)

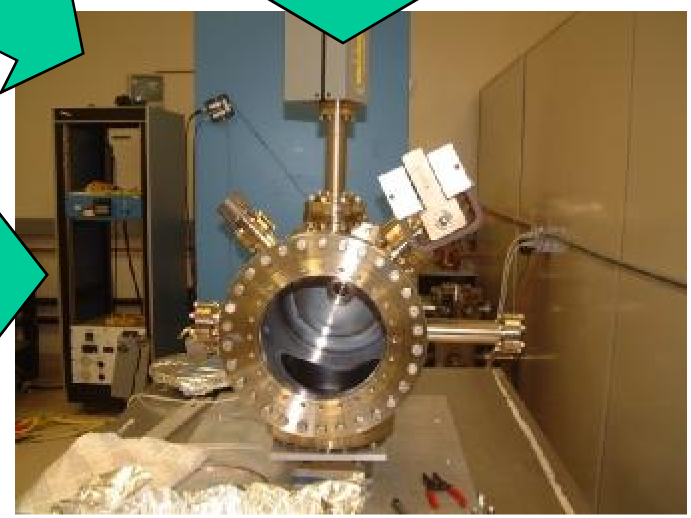
304SS without (blue) and with (red) electroplishing and vacuum firing



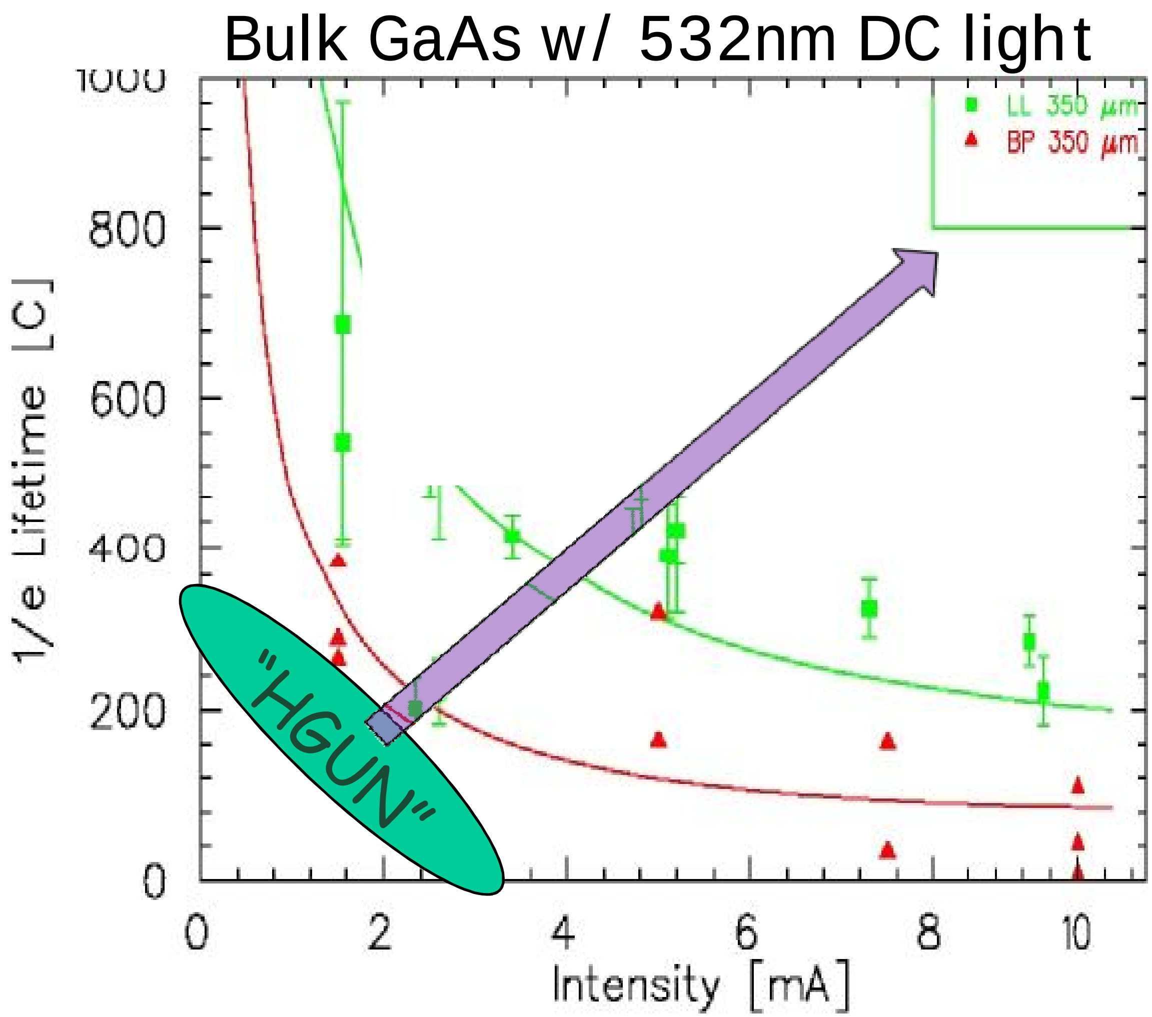
NEG coating
(Ti/Zr/V)
100 hrs @ 70 C
200 L/sec







CEBAF e- source: current & lifetime



Improve vacuum
- Reduce surface area
- 400 C bake
- Ion pump = Gas Source?

Limit "bad" electrons
- Eliminate FE
- Laser handling

Increase QE
- Longer heat clean
- Better vacuum

High-P Photocathode

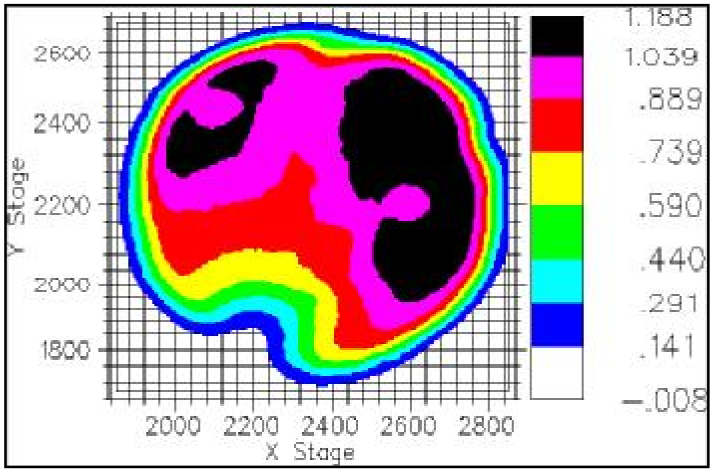
J. Grames et al., in AIP Conference Proceedings 915, p. 1037-1044 (2006).

1 milliAmp demo from High-P Photocathode*

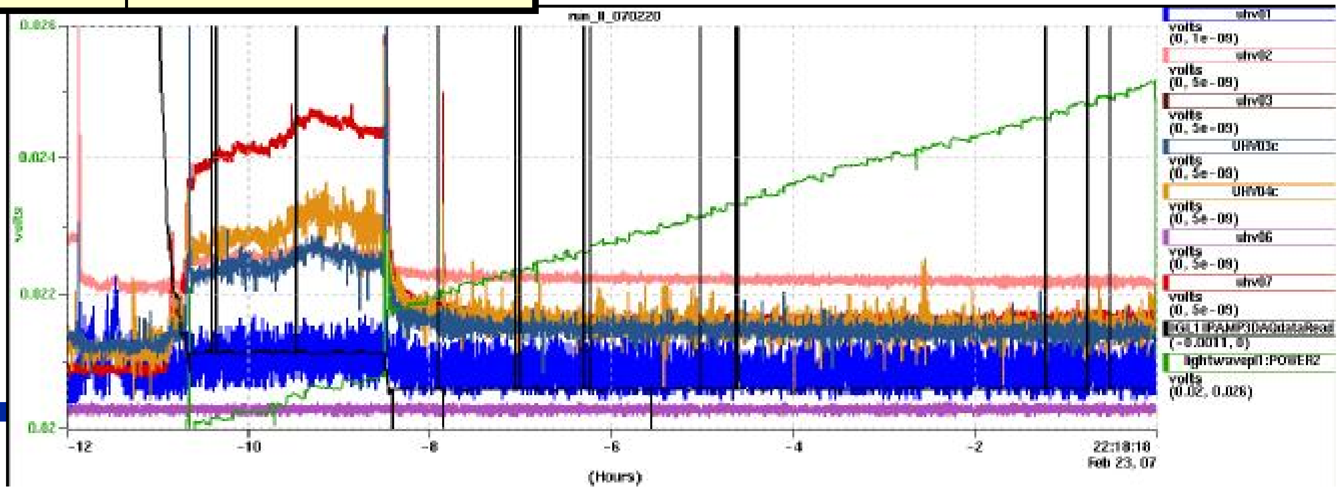
Parameter	Value
Laser Rep Rate (CW)	**499 MHz**
Laser Pulse Length	**30 psec**
Wavelength	**780 nm**
Laser Spot Size (FWHM)	**450 mm**
Average Current	**1 mA**
Run Duration	**8.25 hr**
Extracted Charge	**30.3 C**
Charge Lifetime	**210 C**
Areal Charge Lifetime	**160 kC/cm^2**

*** Note: did not measure polarization**

High Initial QE [%]



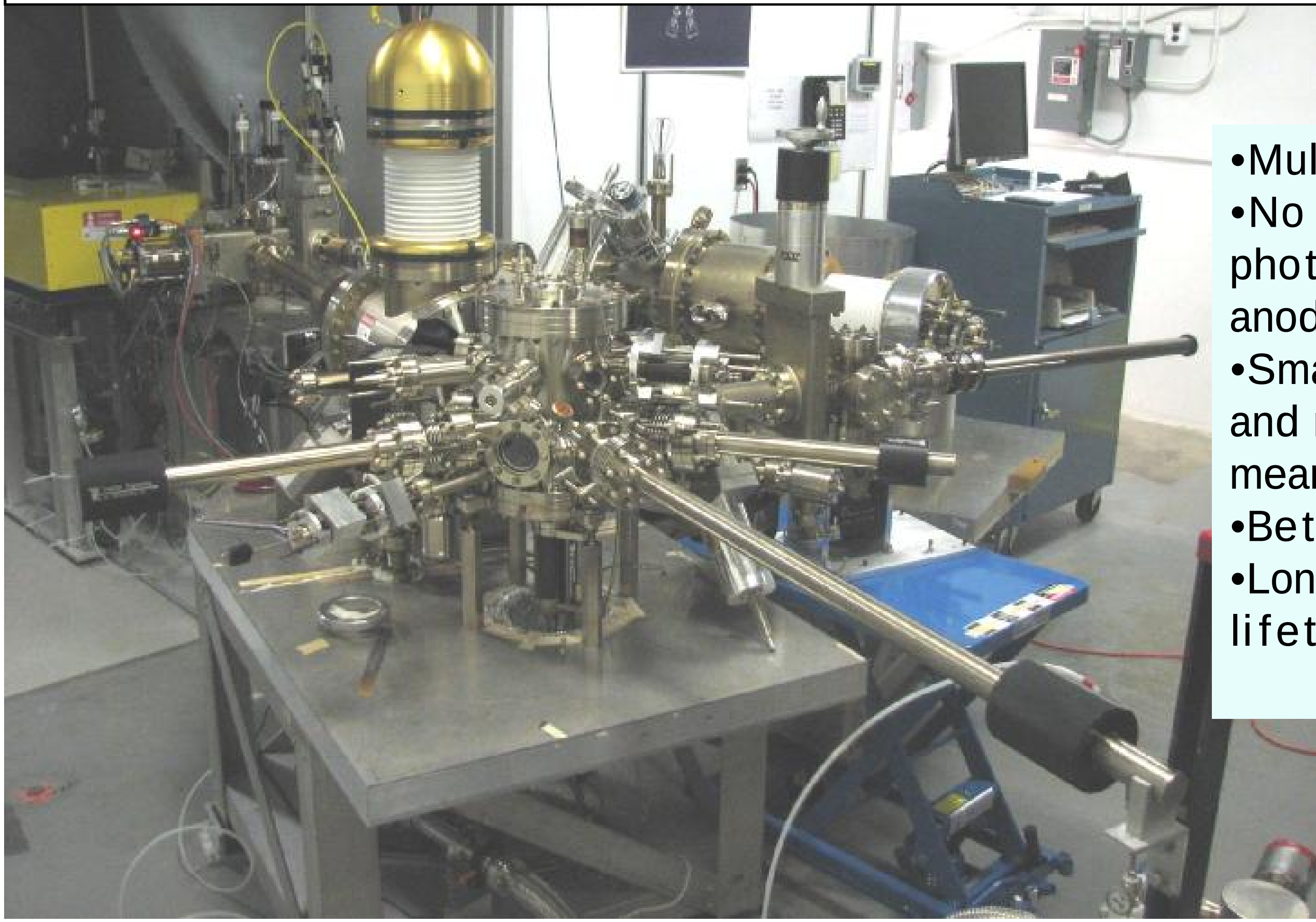
Vacuum signals
Laser Power
Beam Current



Jefferson Lab

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

Future CEBAF Photoinjector Improvements

Design and build compact gun operating at 200 kV

- **Improve use of beam for Qweak & PREX**
  - **Use inverted ceramic insulator**
  - **Field emission reduction via EP/BCP and HPR**

More on these in a moment…

Develop modeling expertise

- **Cathode/anode design, Wien filter spin rotator, etc.**

Increase laser power

- **Improve doubling efficiency (1560 nm to 780 nm)**

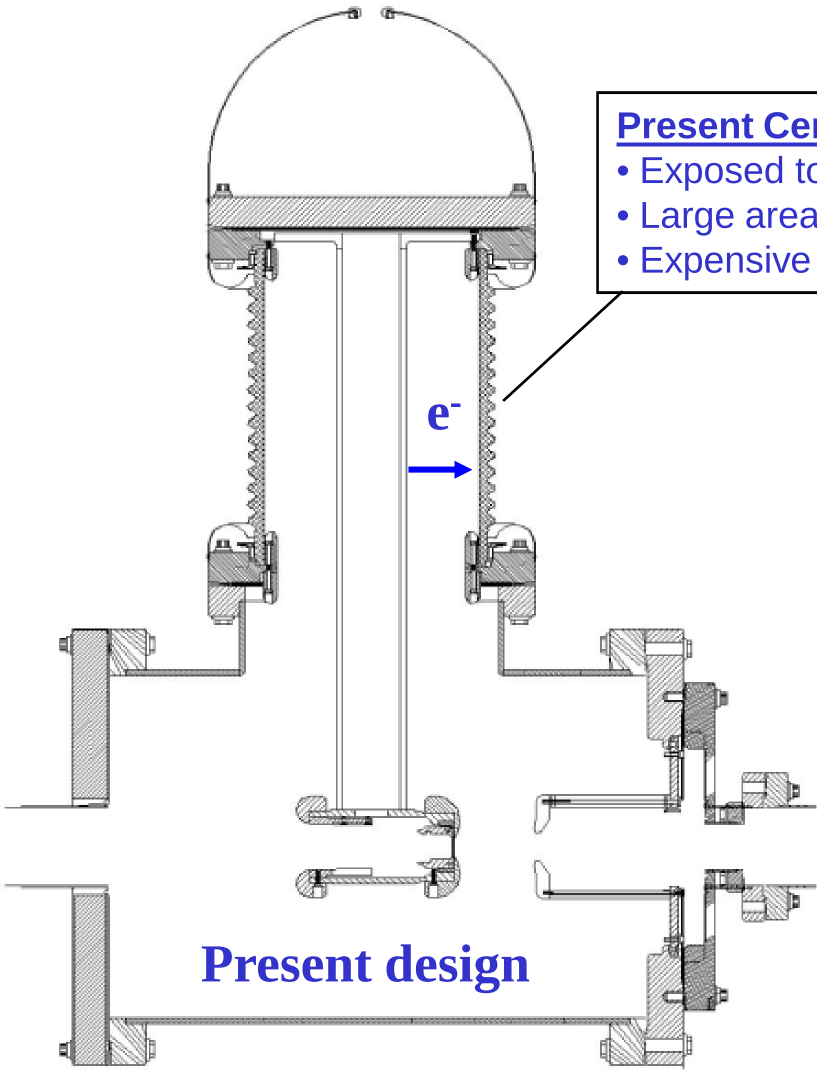
Improve gun vacuum

- **Reduce out-gassing rate by high temperature baking**
- **Understand limitations of pumps and gauges**

Complete polarimeter projects

- **Finish "1%" study of 5 MeV Mott, commission 500 keV Mott**

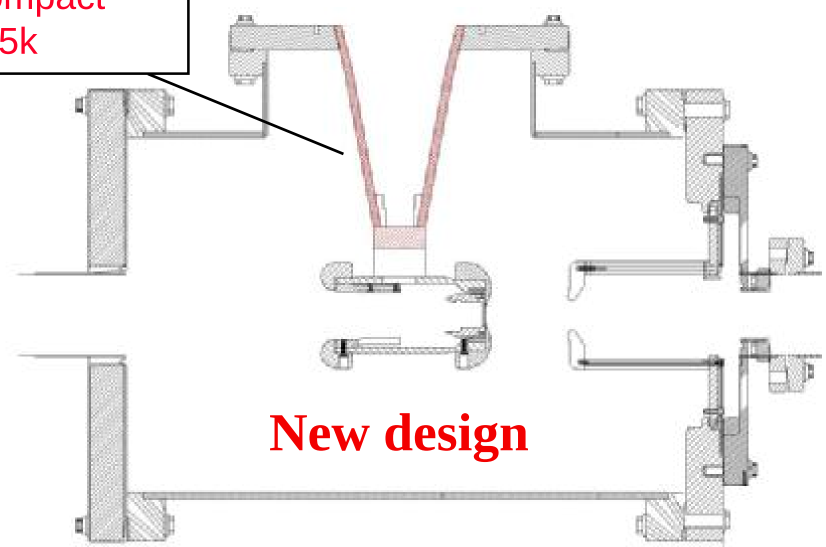
Build Higher Voltage Inverted Gun



Present Ceramic
- Exposed to field emission
- Large area
- Expensive (~$50k)

Medical x-ray technology

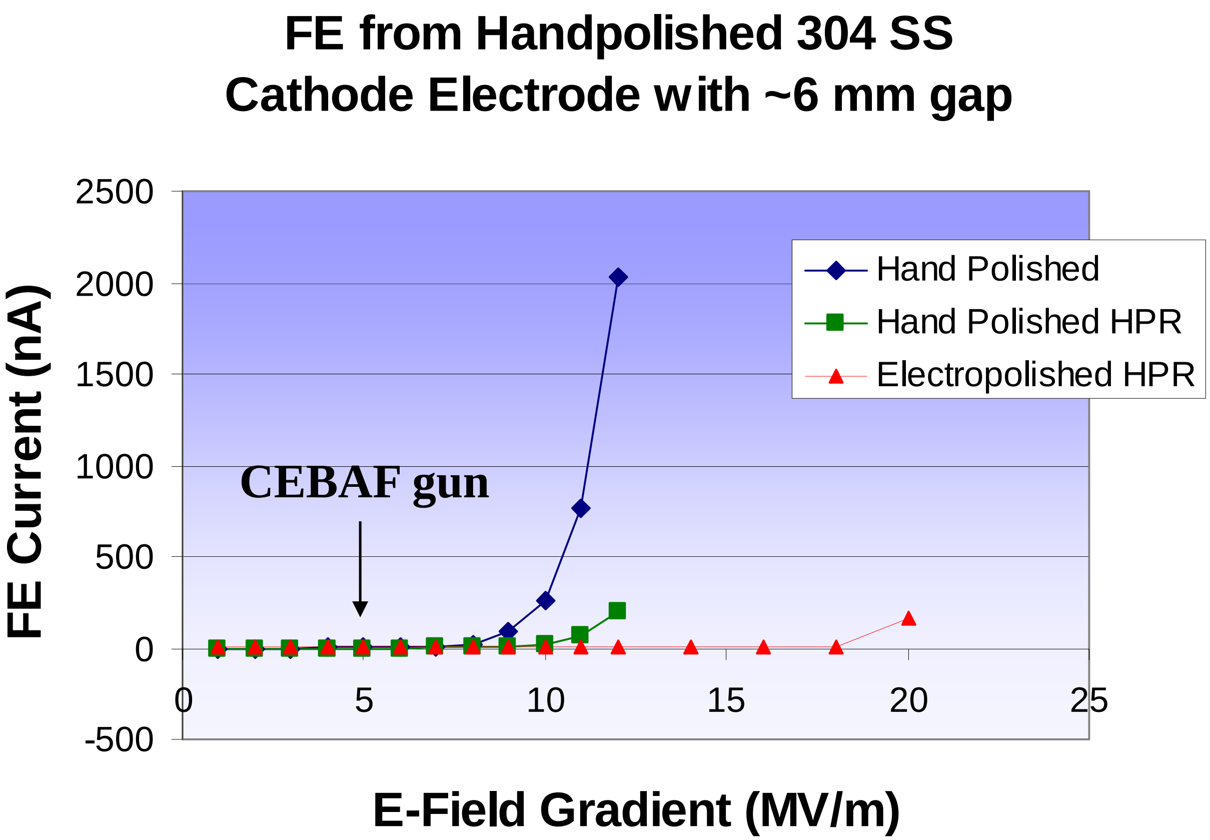
New Ceramic
- Limited FE
- Compact
- ~$5k

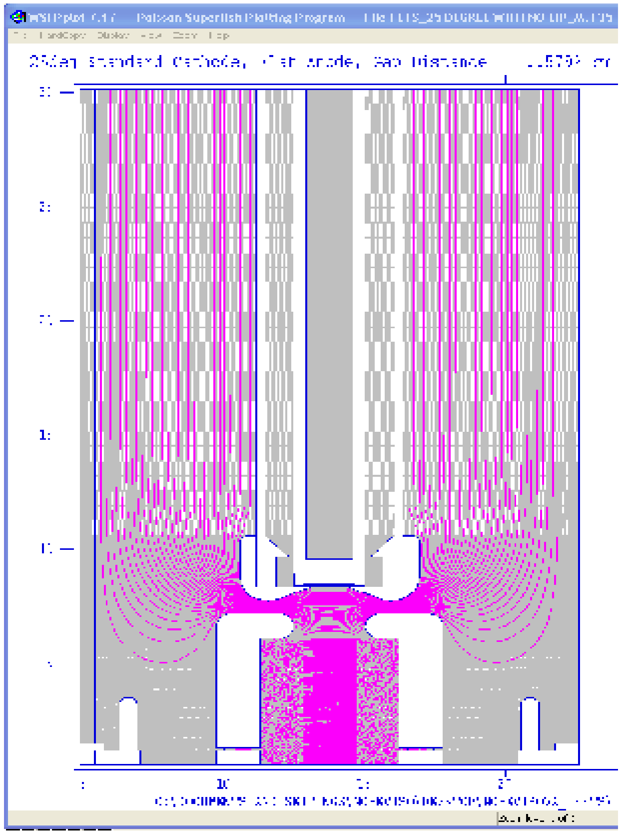


Eliminate Field Emission

Implement the SRF-cavity technique "high pressure rinsing"

<u>Recent work of Maria Chevtsova, Ken Surles-Law with shaped electrodes</u>





Ken is collaborating with SRF Institute to build single crystal Niobium electrodes.