Polarized Photoguns and Prospects for Higher Current

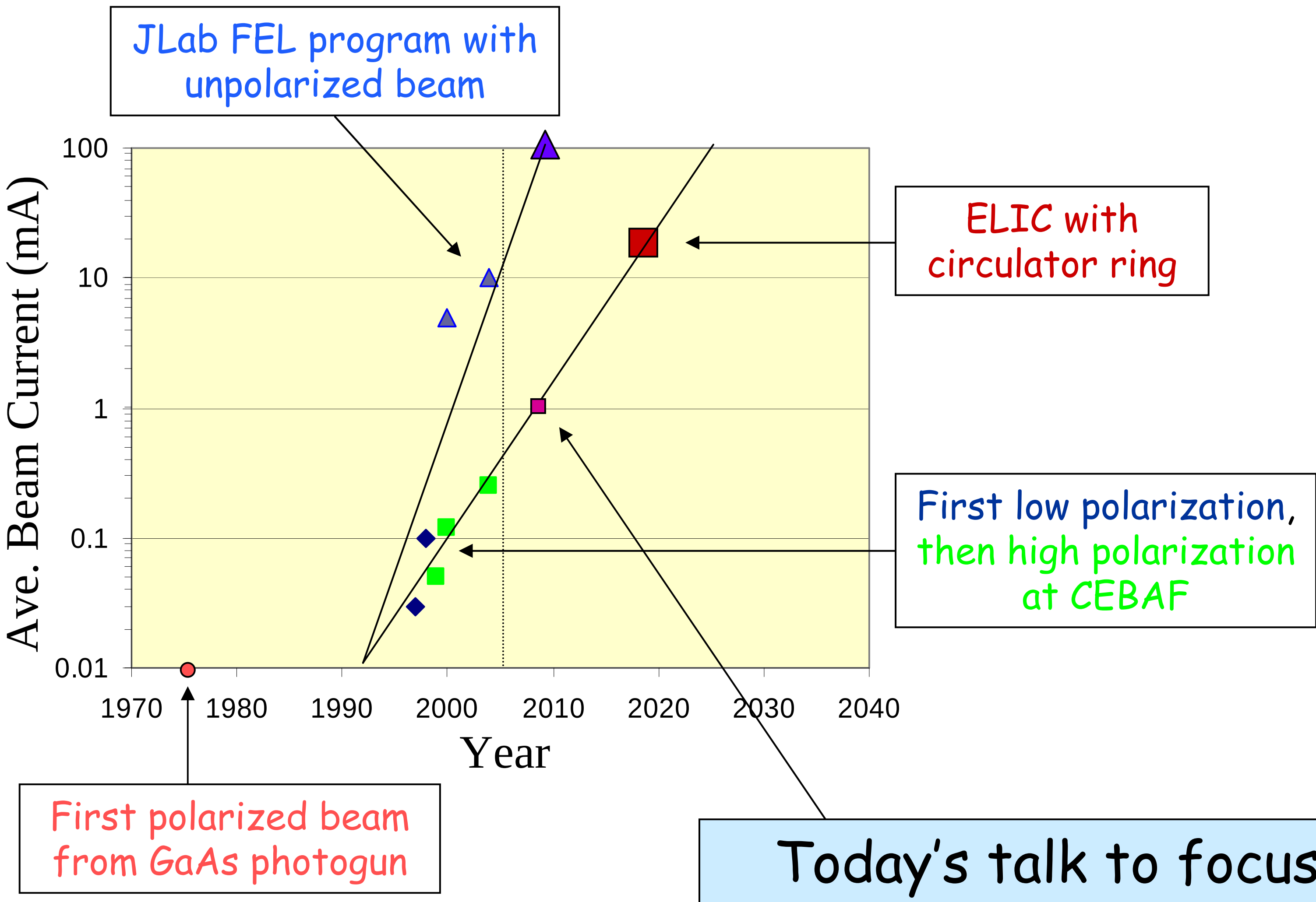
More specifically:

What will it take to provide 1 mA at 85% polarization?

M. Poelker
Jefferson Lab

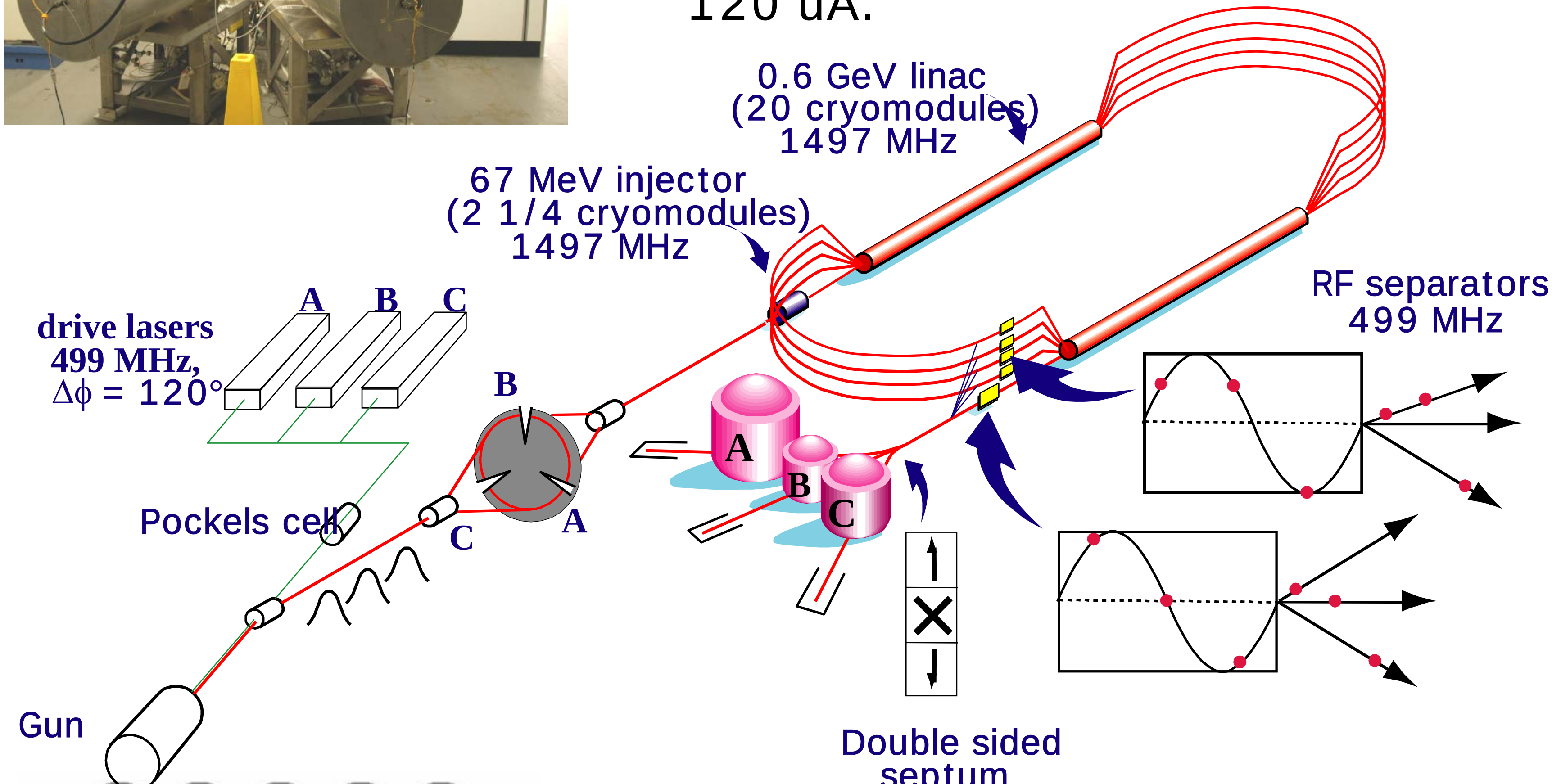
ERL Workshop
Jefferson Lab
March 19 -22, 2005

Plot from EIC Workshop, Jefferson Lab, March 2004



Today's talk to focus on modest extrapolation to 1 mA at 85% polarization

- Only DC high voltage GaAs photoguns are used at CEBAF
- All beam originates from ~ 0.5 mm spot on cathode
- Halls A and C can take up to 120 uA.

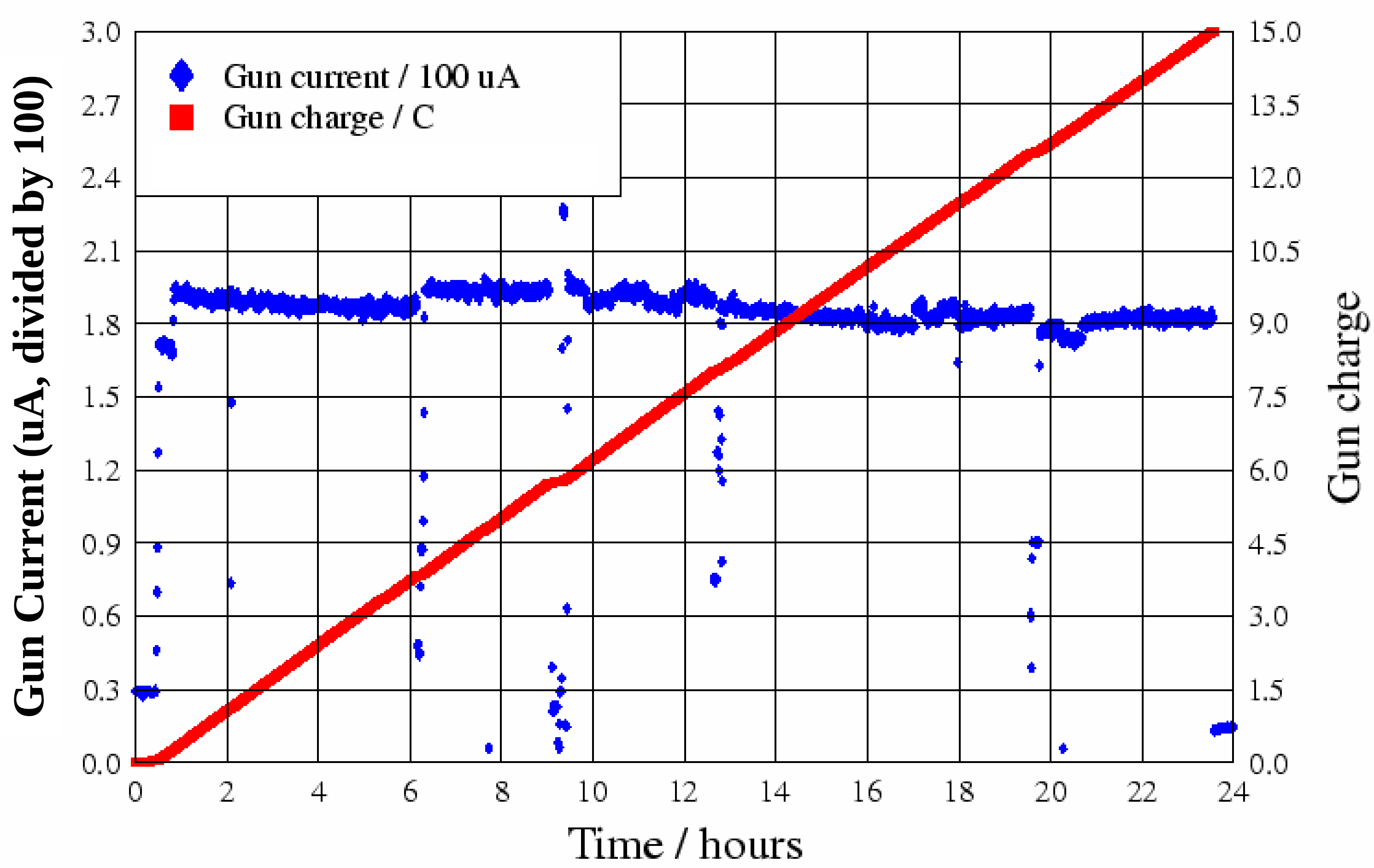


Thomas Jefferson National Accelerator Facility

Operated by the Southeastern Universities Research Association for the U.S. Dept. of Energy

A Good Day at CEBAF…

Uninterrupted beam with ~ 200 uA extracted from gun.
(Mostly, we operate near 100 uA)



What will it take to deliver 1 mA at high polarization?

This represents an improvement of state-of-the-art by factor of 5 to 10.

- Good photocathode material
    - Two commercial vendors
- High power modelocked Ti-Sapphire lasers with GHz repetition rate
    - One commercial vendor for rep rates to 500 MHz
    - One homemade system that needs work
- Good gun lifetime
    - Good static vacuum
    - Maintain good vacuum while delivering beam
- Reliable hardware: lasers, gun and diagnostics.

Commercial Photocathode Material

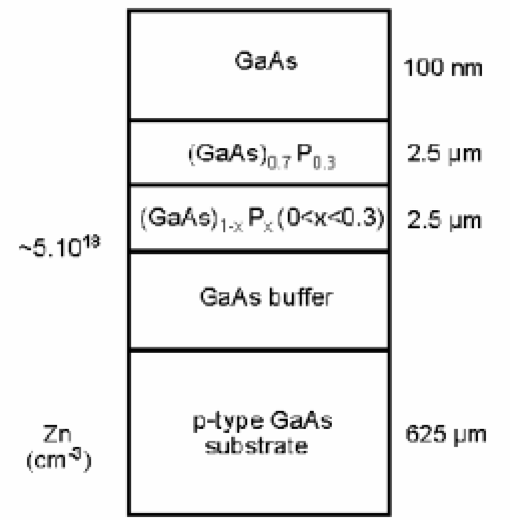
Strained GaAs from Bandwidth Semiconductor (Hudson, NH)

- Polarization ~ 75% with 0.15% QE at 855 nm
- Very reliable vendor, used for many years at CEBAF
- Large 3" diameter wafers, MOCVD, $4.5K/each
- Easily anodized, easily cleaned with atomic hydrogen.
- Mild charge limit behavior when photocathode is "old".
- Large QE anisotropy (or analyzing power), ~ 12%

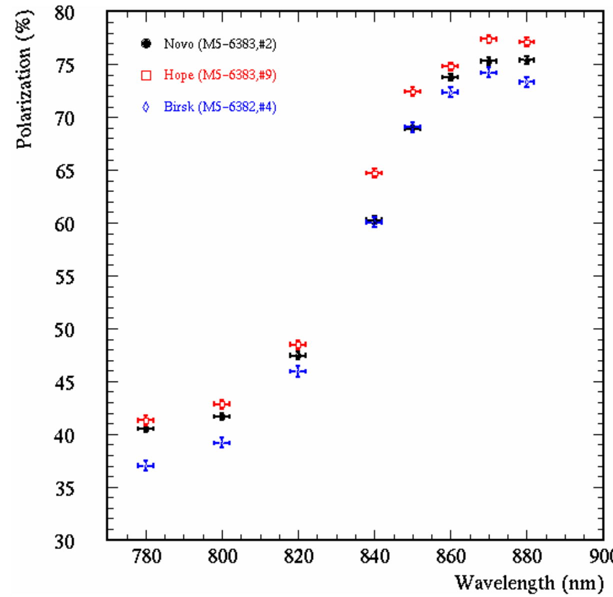
Strained Superlattice GaAs from SVT Associates (Eden Prairie, MN)

- Polarization ~85% and typical initial QE 1% at 780 nm
- Established vendor, new to photocathode business.
- 2" diameter wafers, MBE, $6.3K/each
- Arsenic capped
- Tough to anodize because samples cannot be hydrogen cleaned
- Experience to date: pronounced charge limit problems.
- Small QE anisotropy, ~ 3%.

Items in red = "bad"



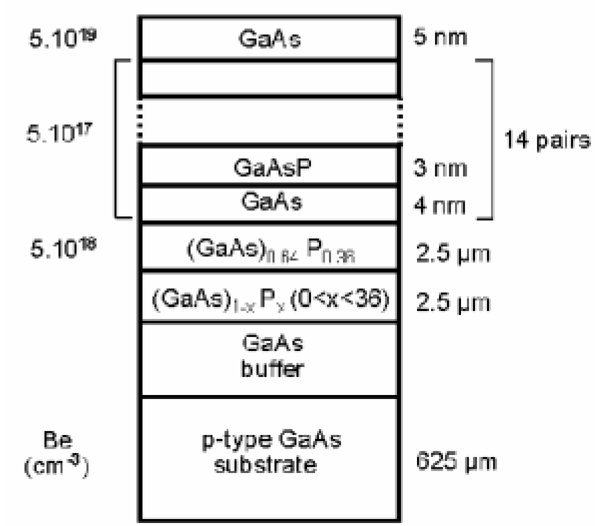
Strained-layer GaAs



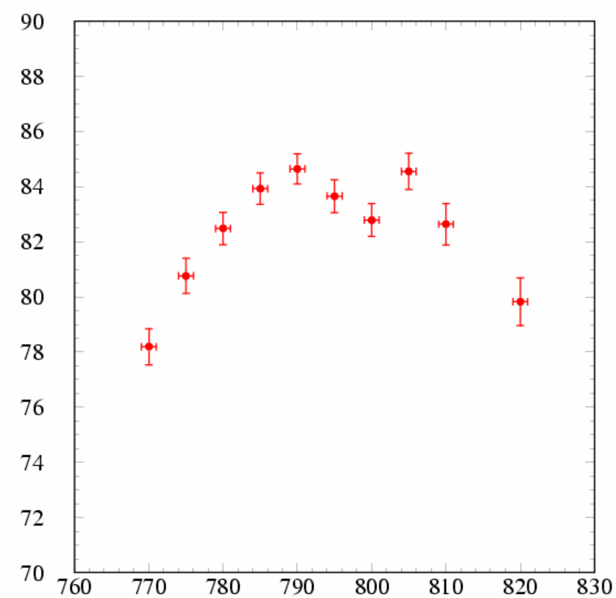
Strained GaAs From Bandwidth Semiconductor

Pol ~ 75%

QE ~ 0.15%



Strained-superlattice GaAs



Strained Superlattice GaAs from SVT Assoc.

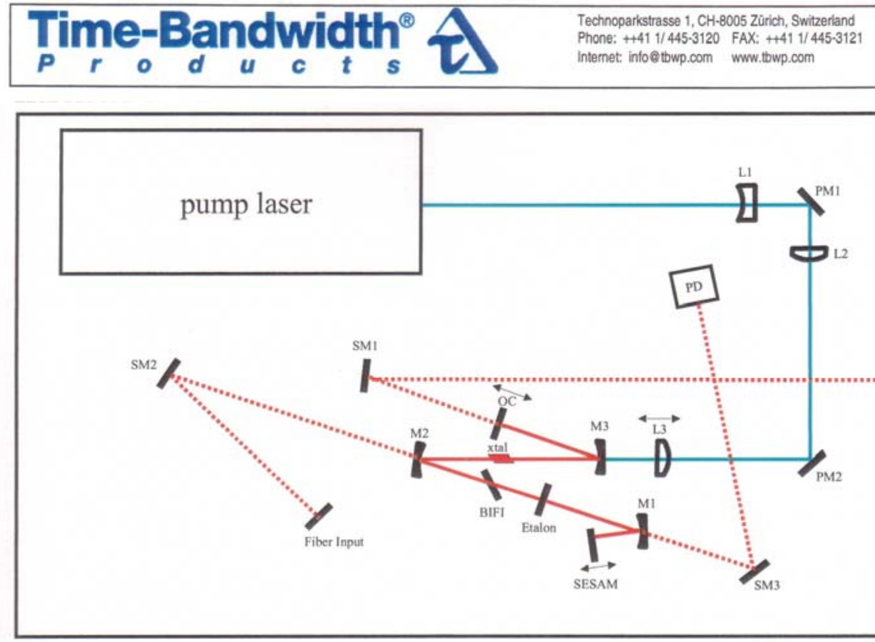
Pol ~ 85%

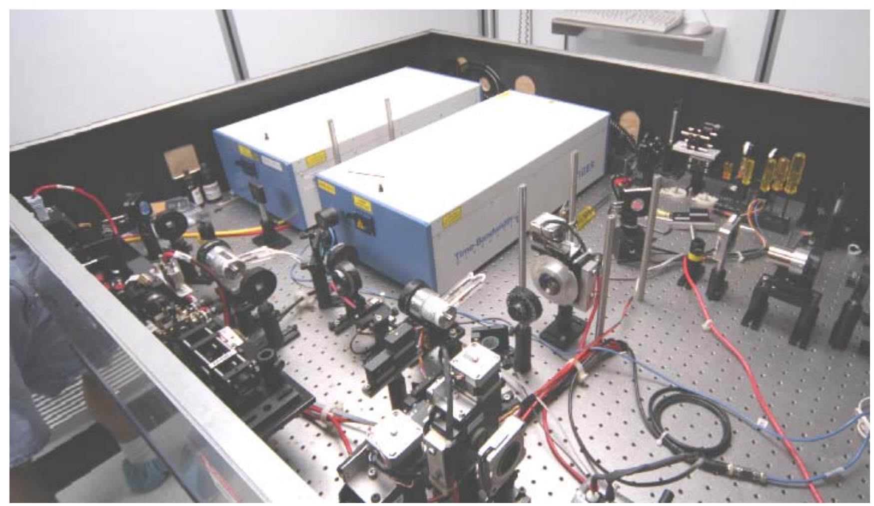
QE ~ 1%

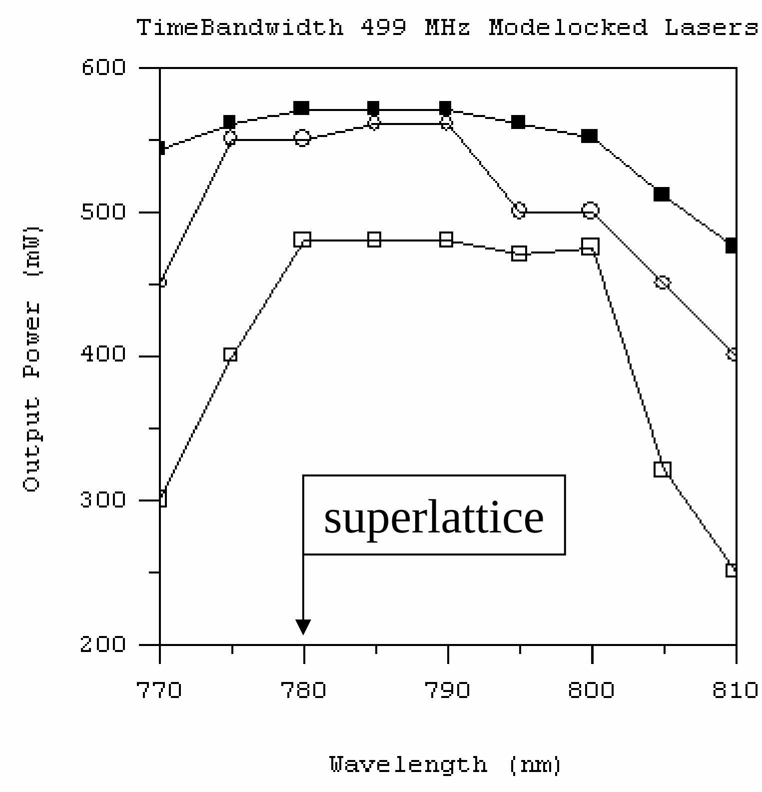
Data from M. Baylac

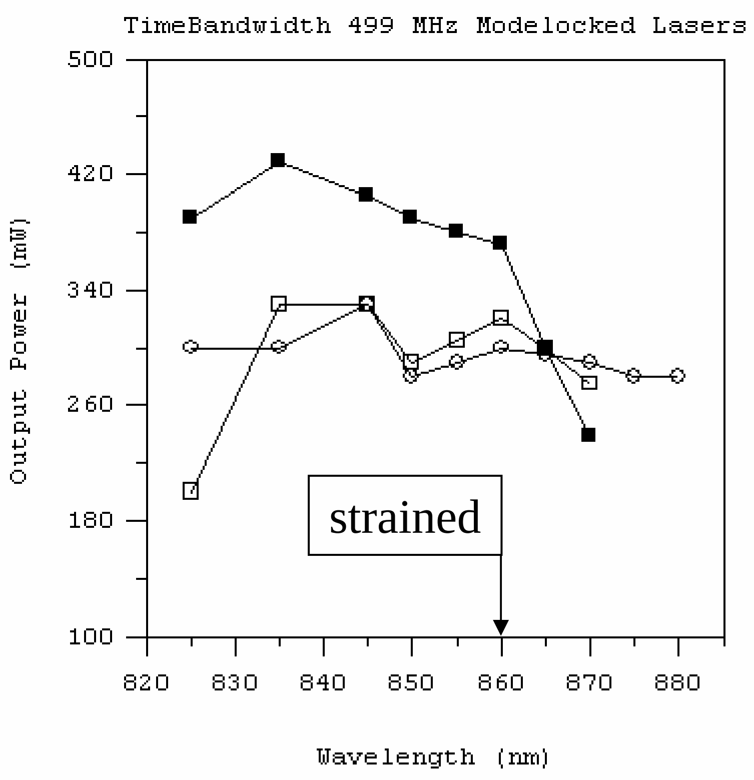
Modelocked Ti-Sapphire Lasers from TimeBandwidth

SESAM: passive modelocking for high rep rates









- **Passive modelocking for high rep rates: CEBAF model = 499 MHz**
- **Selectable wavelength ranges near 770 nm or 850 nm**
- **Phase-locked pulse train is stable for days, weeks, months however…**
- **"laser jock" required.**
- **We also purchased a 31 MHz model with ~ 5 m cavity length.**

Maximum Beam Current with Exisiting Commercial Photocathodes and Lasers

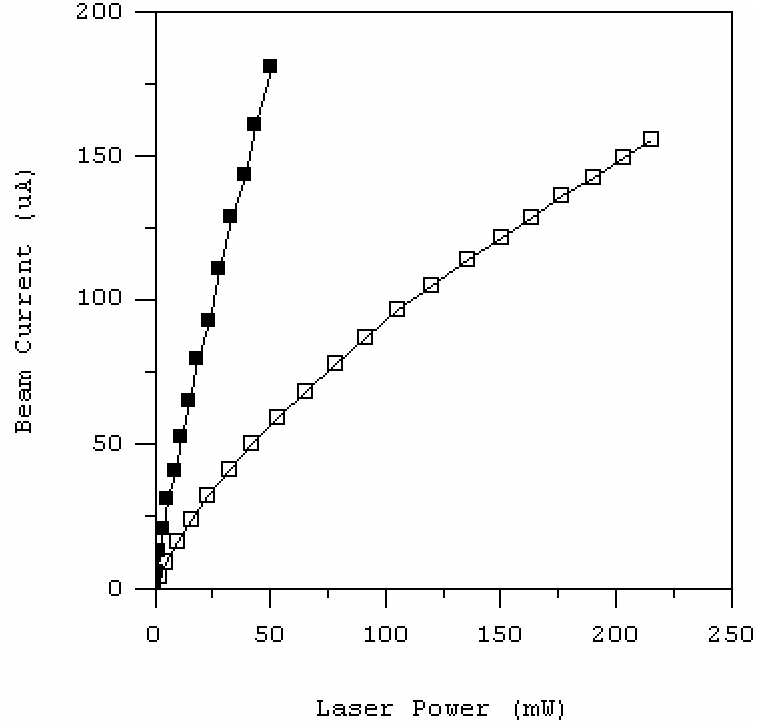
Photocathode Material	Polarization	Max. Initial QE	Max. Laser Power	Max. Current
Strained GaAs	75%	0.15%	300 mW at 860 nm	283 uA
Strained Superlattice GaAs	85%	1%	500 mW at 780 nm	3145 uA

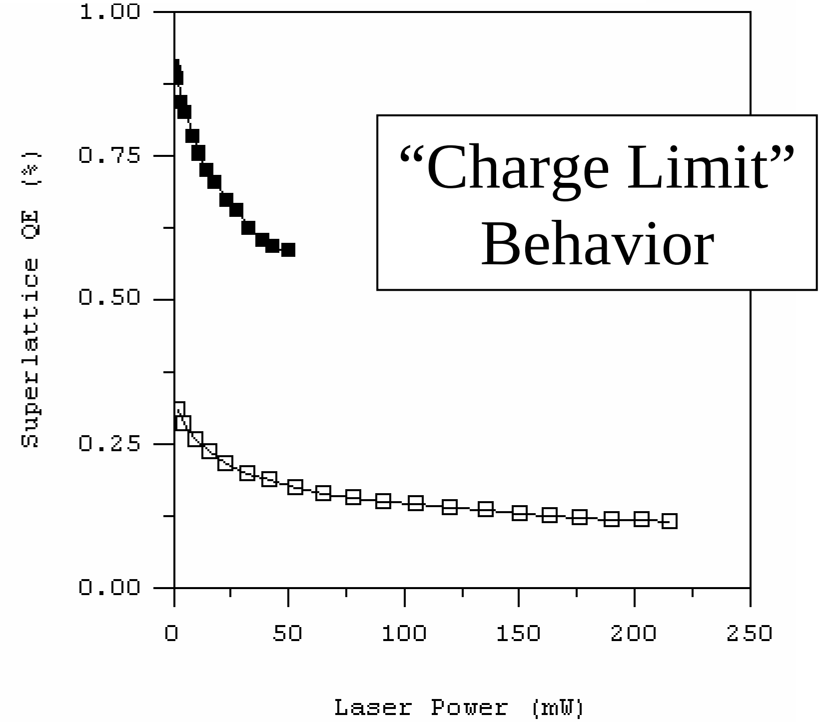
Hooray!

(But not demonstrated)

Problems with Superlattice Photocathodes

After 1 month of beam delivery and 3rd activation





- Photocathode QE not constant with increasing laser power
- Observed Lifetime not so good: 20 C instead of 200 C
- Problems Anodizing and Hydrogen Cleaning: we've had to change CEBAF procedure (tantalum mask, more later)

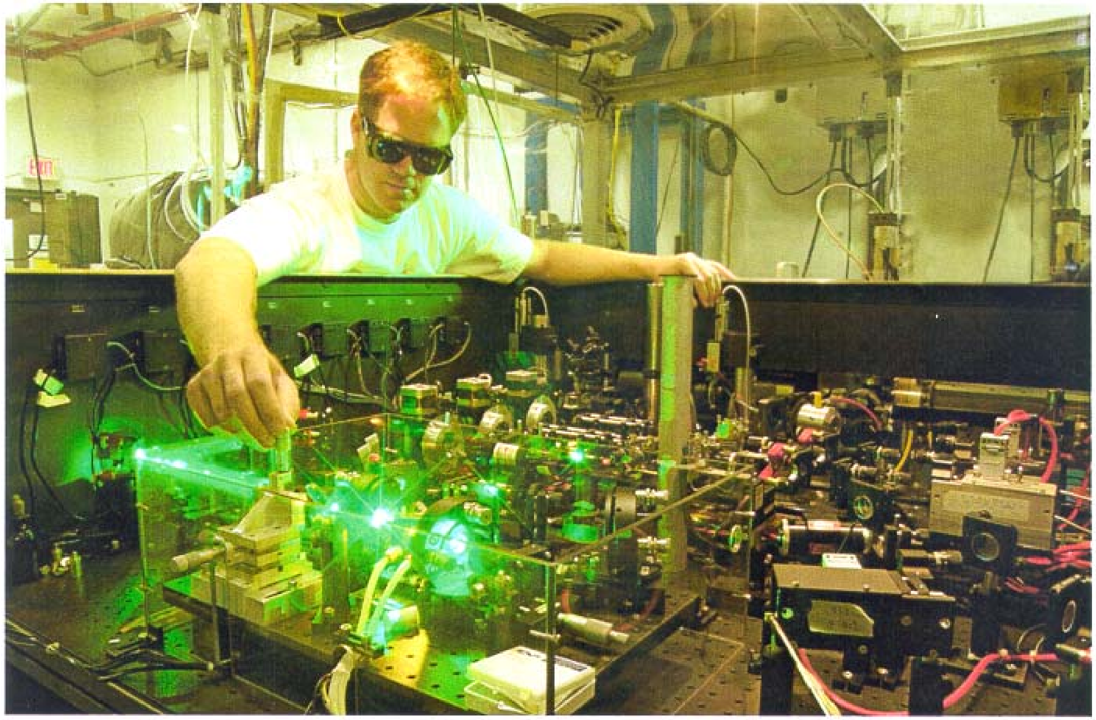
Revise Table to Account for Charge Limit

Photocathode Material	Polarization	Max. Initial QE	Max. Laser Power	Max. Current
Strained GaAs	75%	0.15%	300 mW at 860 nm	283 uA
Strained Superlattice GaAs - With charge limit	85%	0.15 %	500 mW at 780 nm	472 uA

Boo!

And I have not taken into account laser table optical losses.

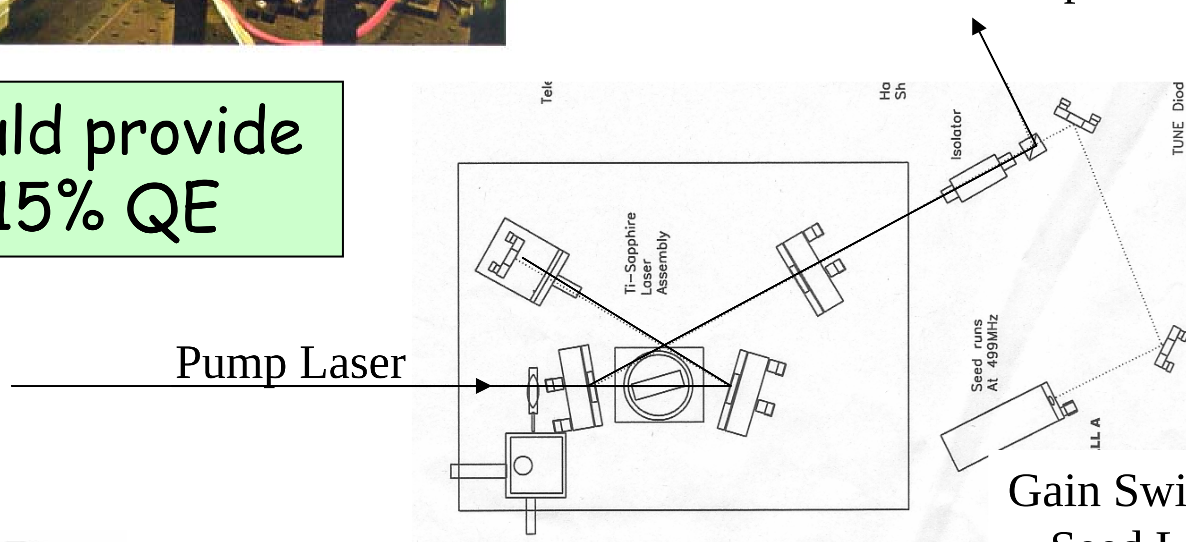
Time to revisit JLab modelocked Ti-Sapphire laser…



Harmonic Modelocked Ti-Sapphire Laser:

- Rep Rates to 3 GHz
- Used at CEBAF, 400 mW
- Lab version produced 2W
- Needs active stabilization

2 Watts would provide
1.8 mA at 0.15% QE



C. Hovater and M. Poelker, Nucl. Instr. And Meth. A418, 280 (1998).

What Effects Gun Lifetime?

Ion backbombardment is the mechanism that causes QE degradation (where residual gas is ionized by extracted electron beam – ions are then back-accelerated toward photocathode)

Obtaining and **Maintaining** good vacuum inside gun is critical

- Baseline vacuum inside CEBAF guns 1x10^-11 Torr
  - NEGs + ion pumps
- Maintain good vacuum when extracting beam:
  - There are "good" electrons and "bad" electrons:
  - Deliver the good electrons and eliminate the bad electrons (or at least ensure they hit the vacuum chamber walls far from the gun).

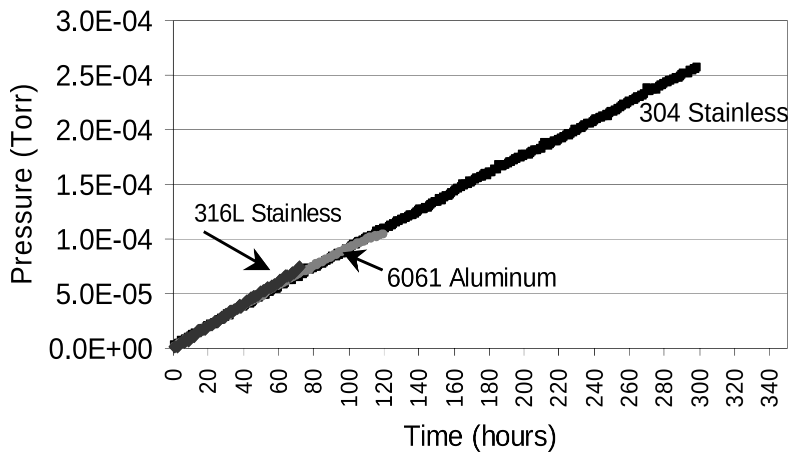
More on Gun Vacuum

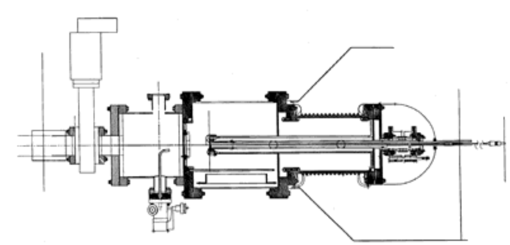
$$\text{Ultimate Pressure} = \frac{\text{Outgassing Rate} \times \text{Surface Area}}{\text{Pump Speed}}$$

	Surface Area (sq cm)	Vacuum Pump	Ultimate Pressure (Torr)	Calculated Pumping Speed (l/s)	Installed Pumping Speed (l/s)
CEBAF Gun	6000	IP & NEG	1.0×10^{-11}	600	~6500

discrepancy

Outgassing Rate ~ 1x10^-12 Torr L/sec cm2

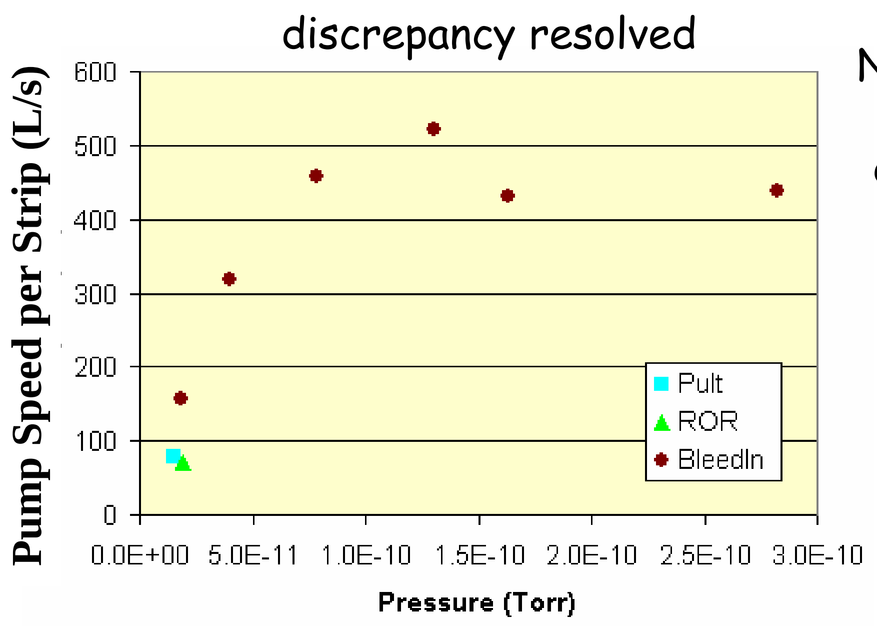




"A Comparison of Outgassing Measurements For Three Vacuum Chamber Materials", P. Adderley, M. Stutzman, *AVS Conf Proceedings*, 2002.

How to Improve Gun Vacuum?

Preliminary measurements



NEG pump speed falls off dramatically at low pressure

Work by M. Stutzman

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

We need; Smaller outgassing rate, Less surface area, More pump speed.

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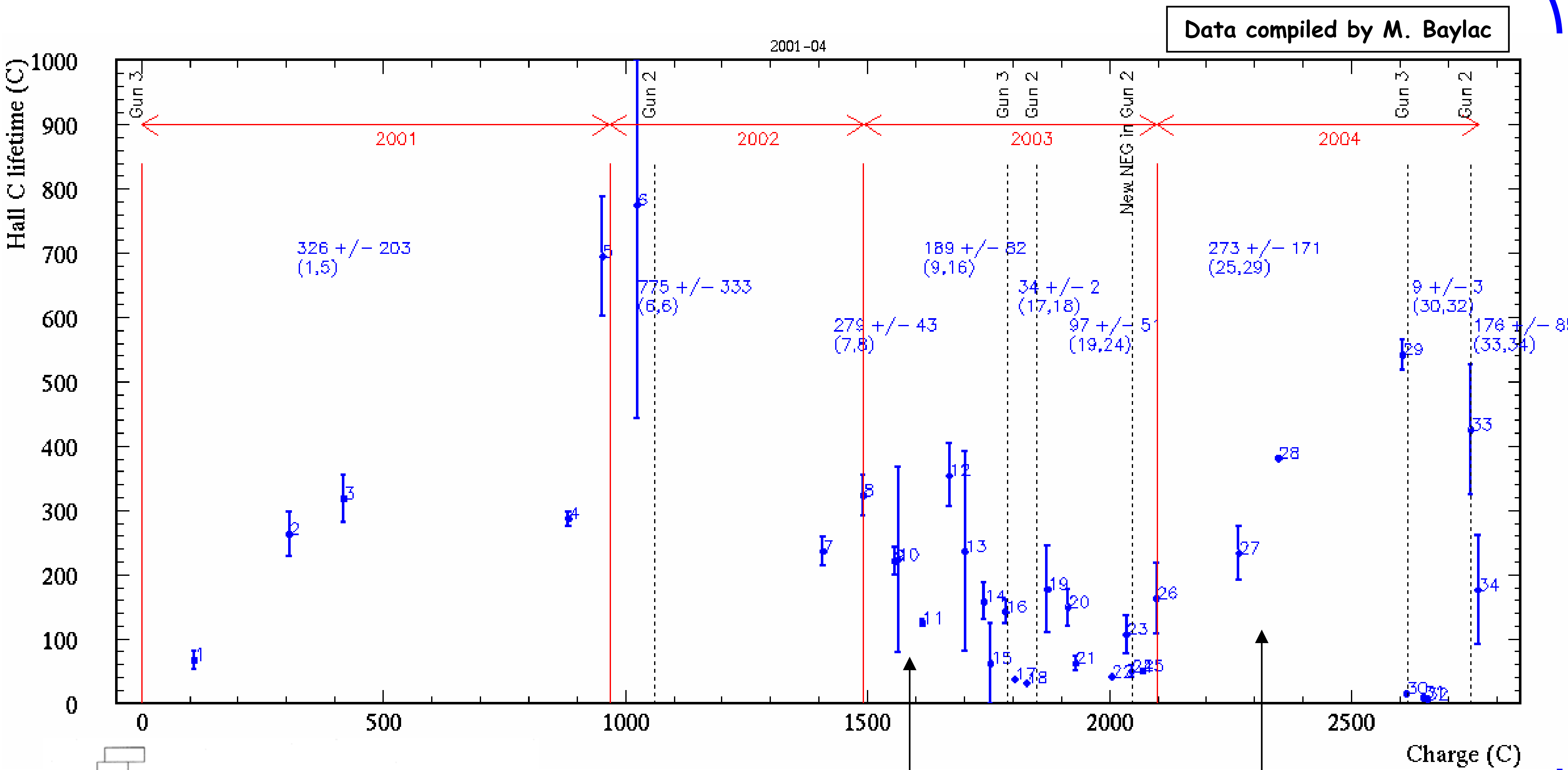
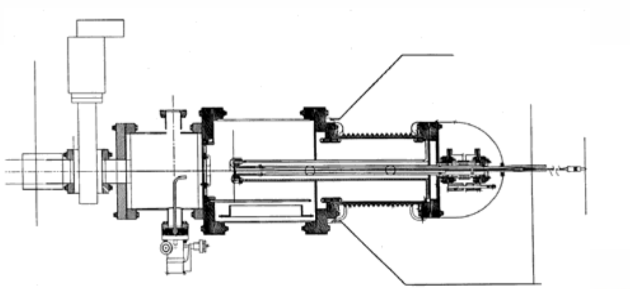
Gun Charge Lifetime Measured over 2001 -2004



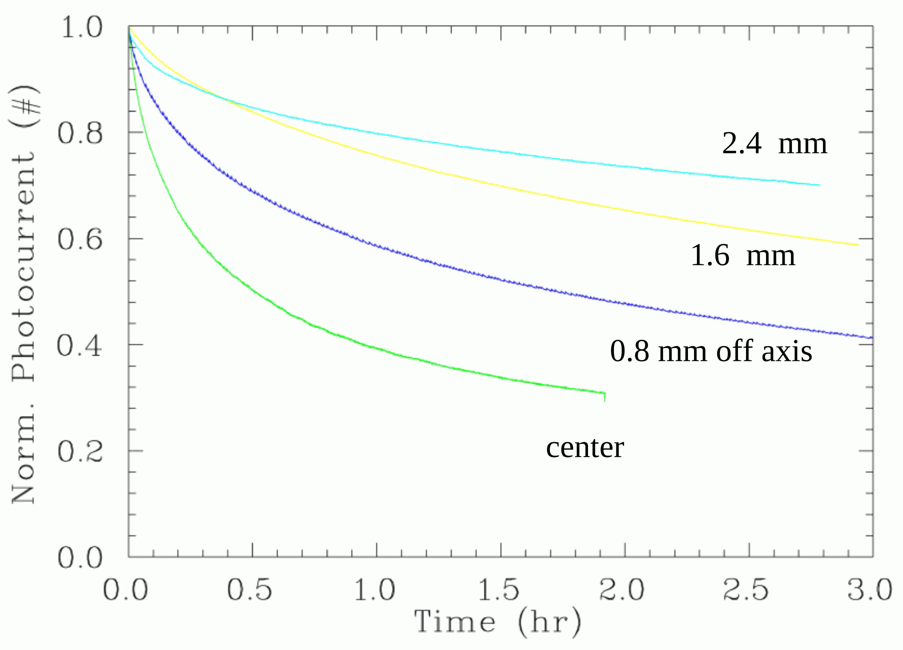


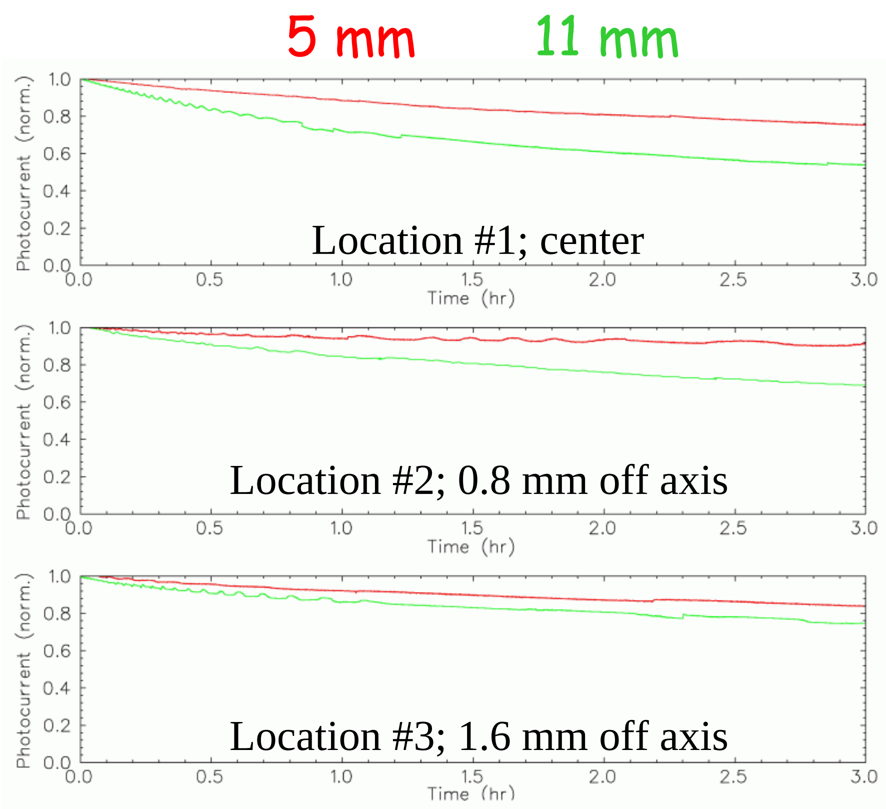
Gun Charge Lifetime Steadily Decreasing

NEG pump replacement Summer 2003 improves lifetime

What Other Factors Effect Gun Lifetime?

- Photocathode Active Area
- Radial position of laser spot on photocathode
- Laser wavelength ?
- Laser spot diameter ?



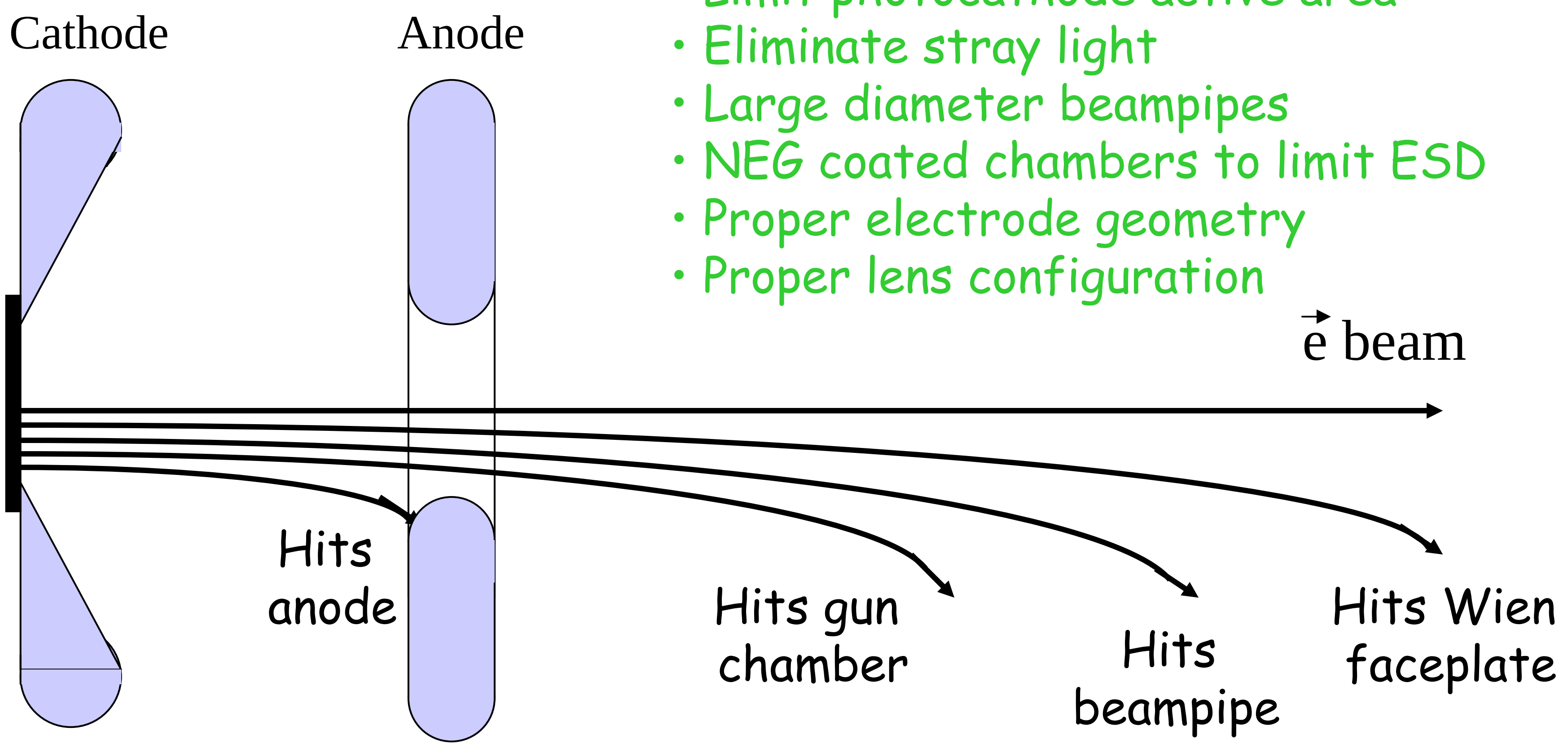


"Lifetime Measuremenst Using JLab Load Locked Gun", J. Grames, prepared for PST 2003 Workshop, Novosibirsk, Russia

Managing the Extracted Electron Beam

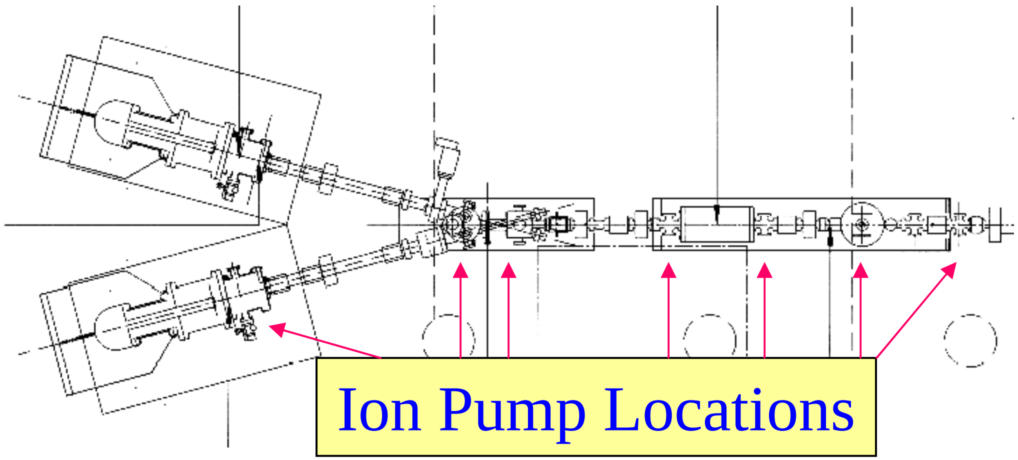
Why is this important? To preserve good vacuum and limit QE degradation associated with ion-backbombardment

- Limit photocathode active area
- Eliminate stray light
- Large diameter beampipes
- NEG coated chambers to limit ESD
- Proper electrode geometry
- Proper lens configuration

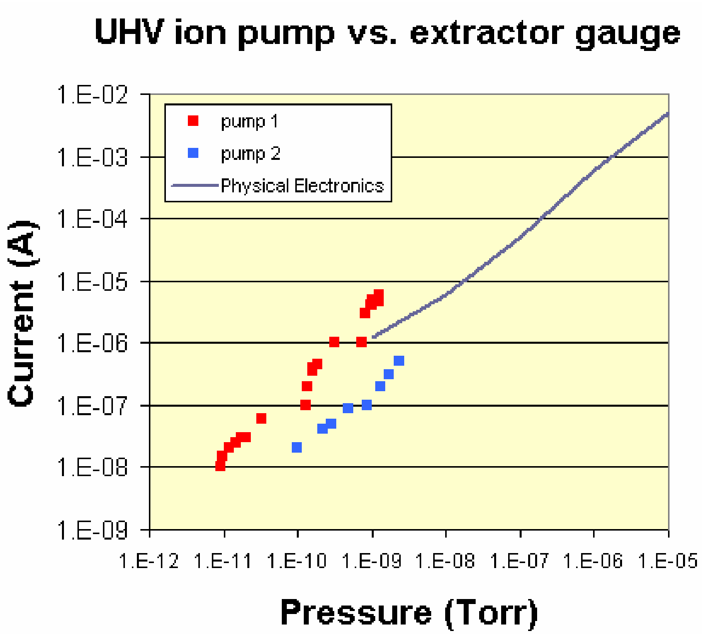


Ion Pump Power Supplies with nanoA Current Monitoring

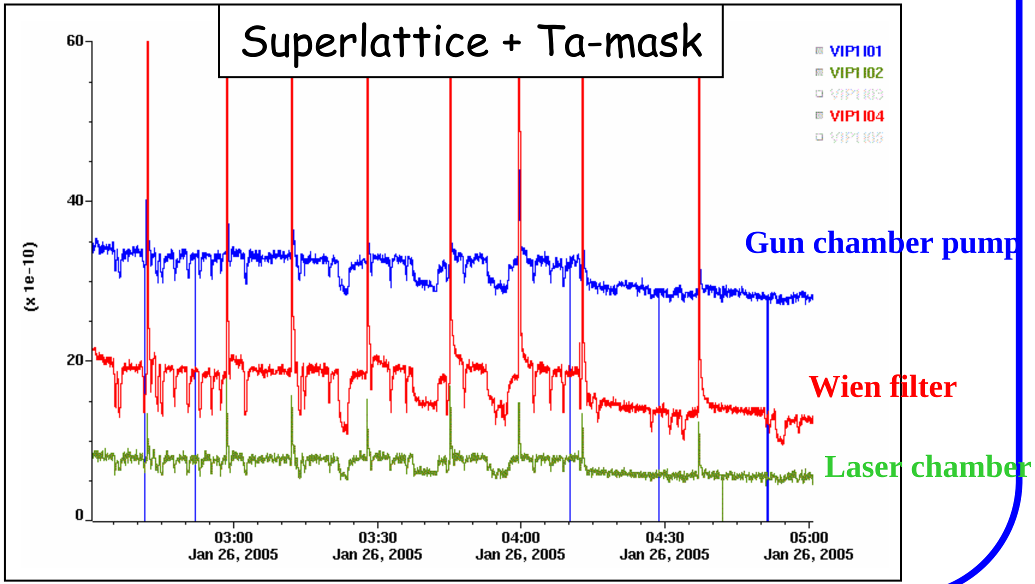
Designed and constructed by J. Hansknecht



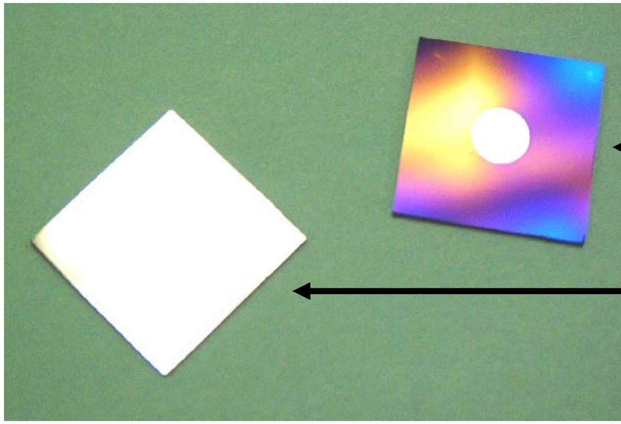
"Free" pressure monitoring at 10^-11 Torr



Pumps detect bad orbit and beamloss



Limiting Active Area via Anodization

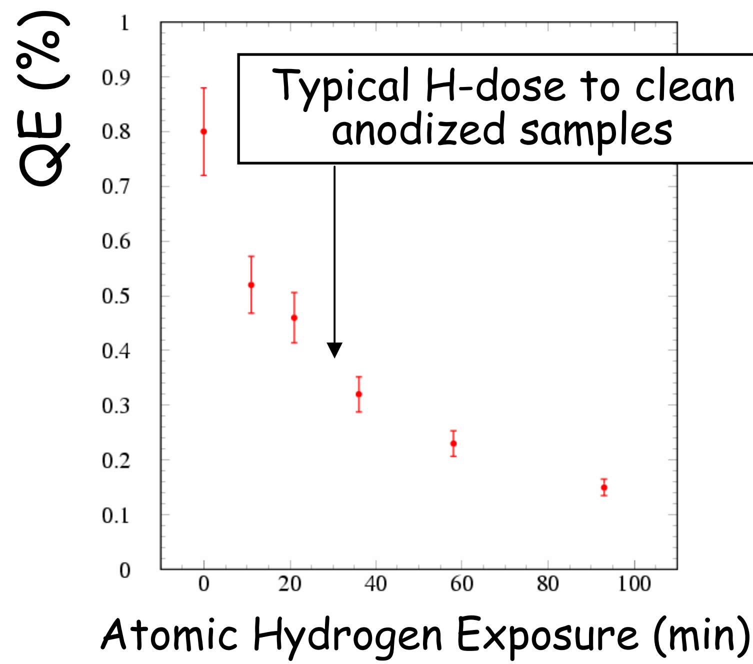


Anodized photocathode

Photocathode "out of box"

We have not successfully anodized superlattice material – it cannot be hydrogen cleaned.

We are using a tantalum mask, which might be the source of unwanted electrons.



"The Effects of Atomic Hydrogen Exposure On High Polarization GaAs Photocathodes", M. Baylac, in press.

Summary

- Only superlattice photocathodes have demonstrated polarization > 80%.
- Only superlattice photocathodes can (in principle) provide 1 mA with existing commercial modelocked Ti-Sapphire lasers.
- Superlattice photocathodes have good initial QE but lifetime at CEBAF has not been as good as for strained GaAs (problems with ta-mask?). QE falls with increasing laser power. More experience needed.
- TimeBandwidth sells reliable modelocked Ti-Sapphire lasers with rep rates to 500 MHz and ~ 500 mW power
- Laser development required for higher rep rates and higher power.

Summary cont.

• NEG pump speed drops rapidly at pressure below 10^-11 Torr. Long lifetime operation at high current will require better vacuum: need better pumps, smaller chamber volume, smaller outgassing rate.

• Managing the extracted electron beam is critical (both "good" and "bad" beam). Groups working on new injectors will benefit from thoughtful modeling of beam that originates from the ***entire*** photocathode.

• Load locked guns are good. New CEBAF design to be installed Sept. 05. Duplicate at Test Cave will be very useful for high current/high polarization tests.

• It would be great to find a diode/amplifier alternative to Ti-Sapphire lasers. Superlattice photocathode support diode ops at 1.55 um.

Gun Issues for ELIC

- Need 80% polarized e-beam.
- Use SVT superlattice photocathode. 1% QE at 780 nm;
  - 6.3 mA/W/%QE
  - ~ 1 W provides 1/e operation at 2.5 mA
- Commercial Ti-Sapp lasers with CW rep rates to 500 MHz provide 0.5 W. Homemade lasers provide ~ 2W.
- Injector micropulse/macropulse time structure demands laser R&D.
- 25 mA operation requires more laser power and/or QE.
- Charge Limit? Yes, at 1.6 nC/bunch and low QE wafers.
- Lifetime? Probably wise to improve vacuum (more later)
- Gun HV ~ 500 kV to mitigate emittance growth.
  - Must limit field emission.

Gun Lifetime

- CEBAF enjoys good gun lifetime;
  - ~ 200 C charge lifetime (until QE reaches 1/e of initial value)
  - ~ 100,000 C/cm2 charge density lifetime (we operate with a ~ 0.5 mm dia. laser spot)
- Gun lifetime dominated by ion backbombardment.
- So it's reasonable to assume lifetime proportional to current density.
- Use a large laser spot to drive ELIC gun. This keeps charge density small. Expect to enjoy the same charge density lifetime, despite higher ave. current operation, with existing vacuum technology.

Gun Lifetime cont.

Lifetime Estimate;

- Use 1 cm diameter laser spot at photocathode.
- At 2.5 mA gun current, we deliver 9 C/hour, 216 C/week.
- Charge delivered until QE falls to 1/e of initial value;

100,000 C/cm2 *1 Wk/216 C * 3.14(0.5 cm)^2 = 360 Wks!
36 Weeks lifetime at 25 mA.

- Need to test the scalability of charge lifetime with laser spot diameter. Measure charge lifetime versus laser spot diameter in lab.

Laser Power and Max QE

- Present state of the art;
  - QE = 1% at ~ 80% polarization (SVT superlattice photocathode)
  - TimeBandwidth SESAM modelocked Ti-Sapphire laser with rep rates to 500 MHz and ave. power ~ 500 mW
  - "Homemade" modelocked Ti-Sapphire laser with rep rates to ~ 3 GHz and ave. power ~ 2 W (C. Hovater and M. Poelker, Nucl. Instr. And Meth. A418, 280 (1998).
- We should be able to deliver 12.6 mA today! Albeit with a CW pulse structure.