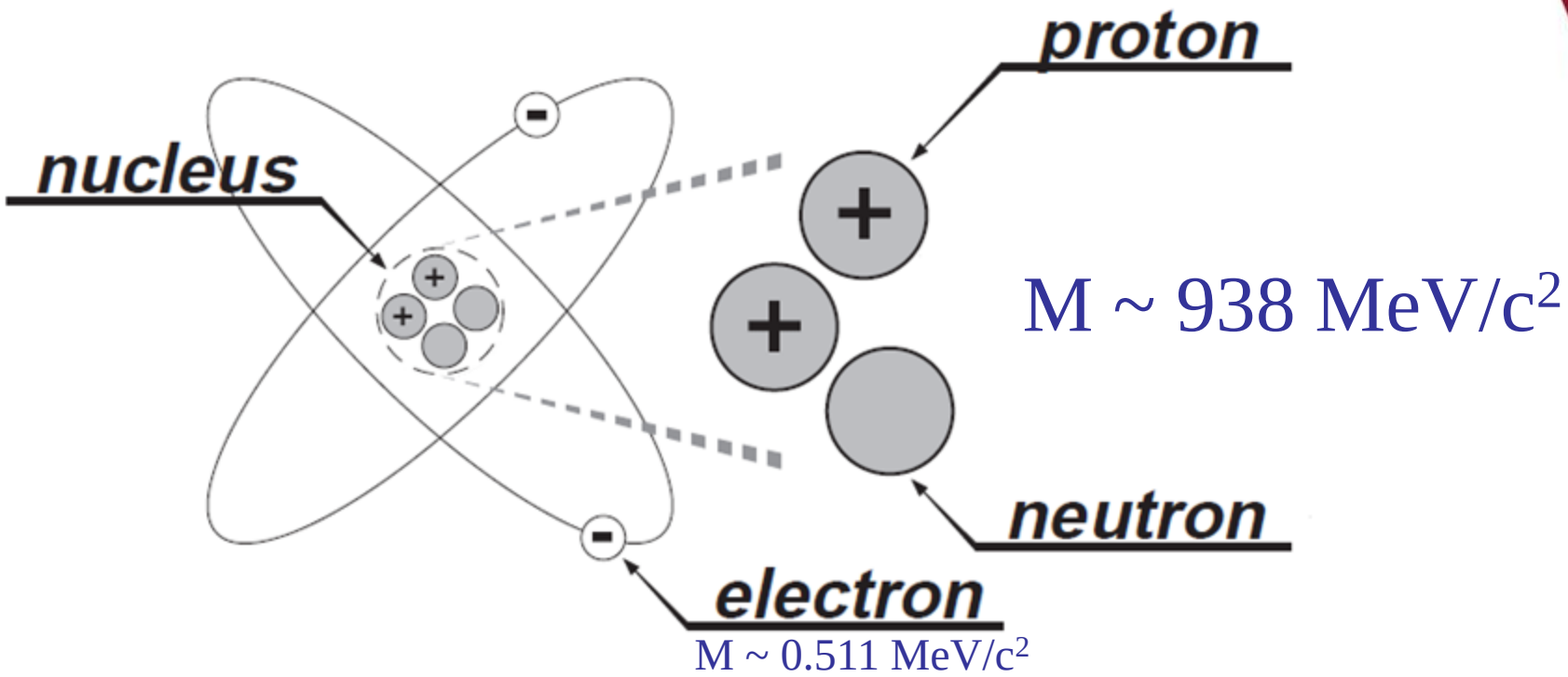
# CEBAF
# Polarized Electron Source

Jim Clark, Matt Poelker, Steve Covert, Phil Adderley,
Riad Suleiman, John Hansknecht, Marcy Stutzman, Joe Grames

JLAB Summer Lecture Series, June 23rd 2011

Jefferson Lab

# What you "are" is what you "see"…

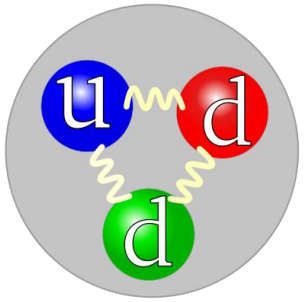



**mass ~ 1/λ ~ energy**

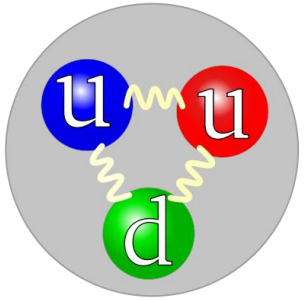
# What to do?

Build a 5 mile long electron microscope!

Electron




Neutron

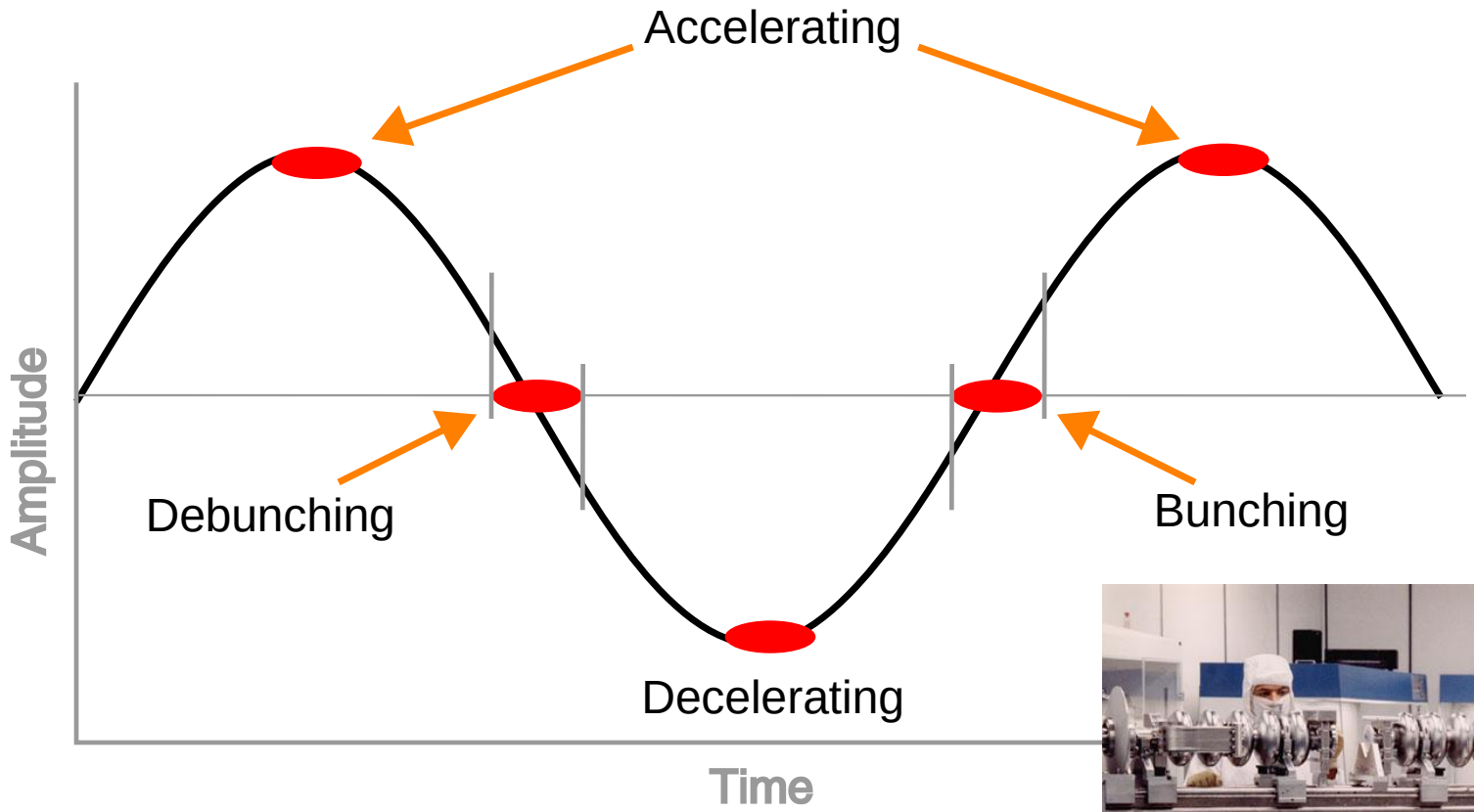



Proton

Make electrons energetic enough ($E_{beam}$) to peek inside proton or neutron ($M_{nucleon}$).

# How to make the electrons “powerful” ?

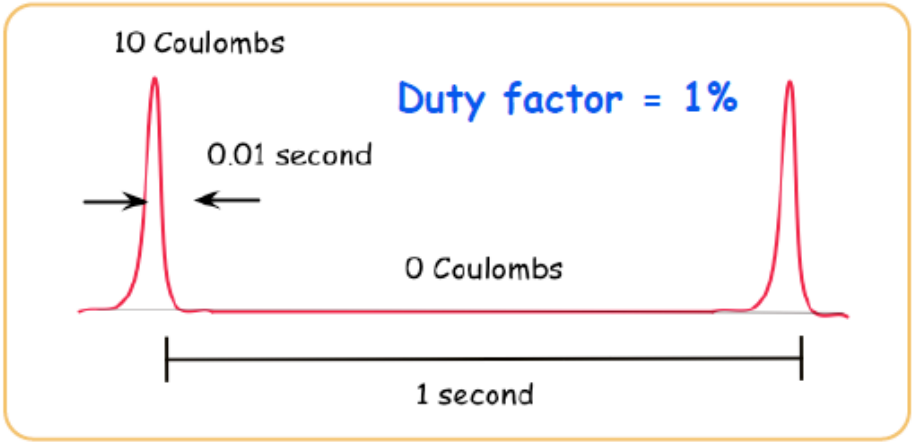
## Use radio(frequency) waves !!!



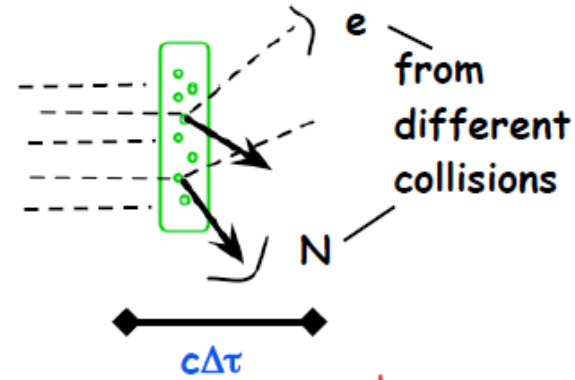

Electrons gain energy on each crest!

# The "C" in CEBAF

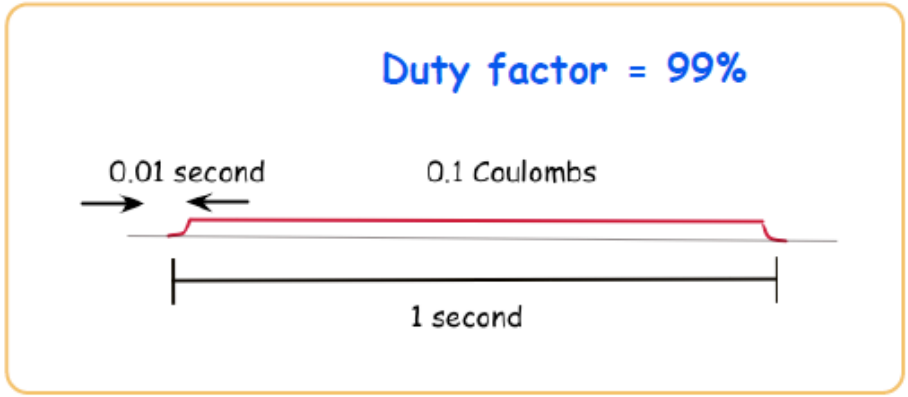
★ Pulsed beams used prior to 1980 (100 mA)



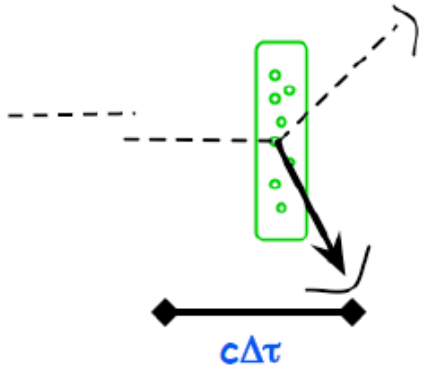

too many electrons in the target over the time interval $\Delta\tau$
lots of random coincidences



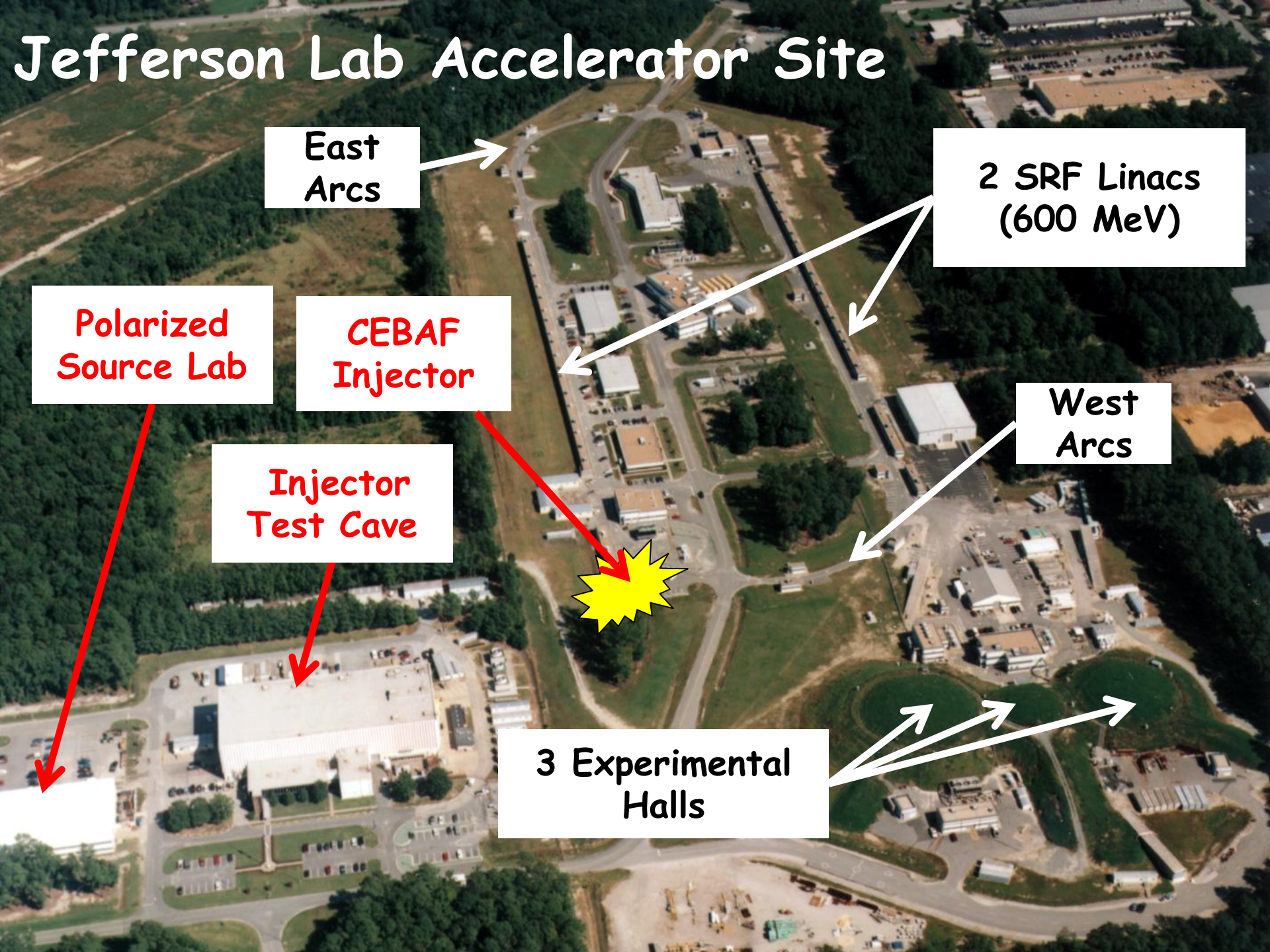

★ Advantages of a continuous beam with the same average current



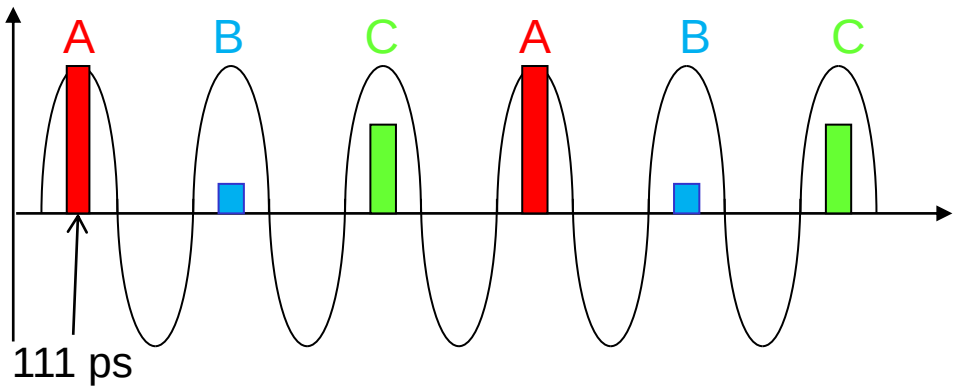

few electrons in the target -- few random coincidences

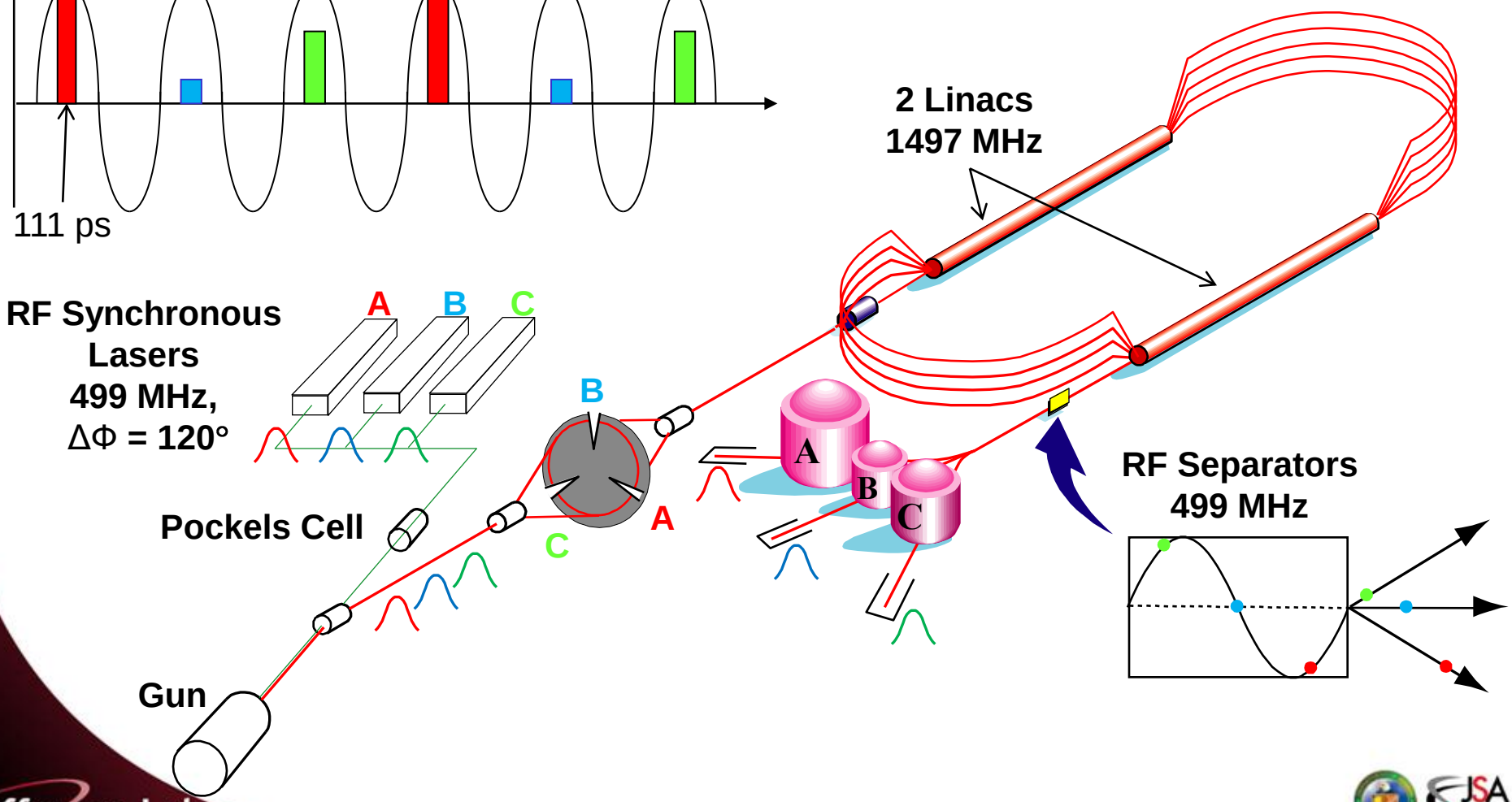


# Jefferson Lab Accelerator Site



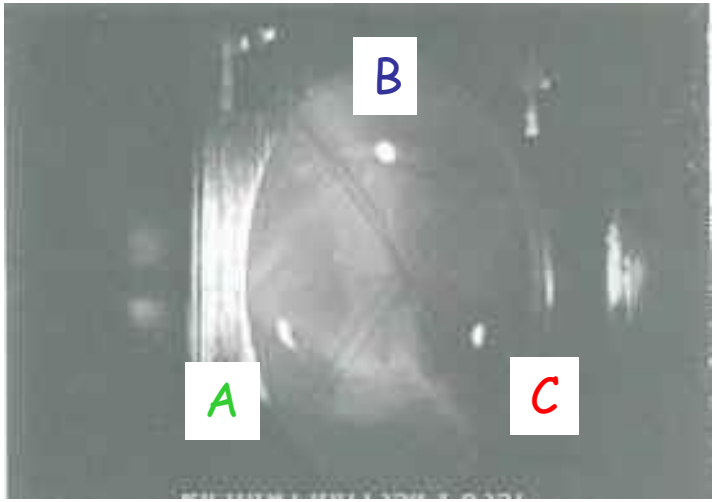
# Continuous Electron Beam Accelerator Facility



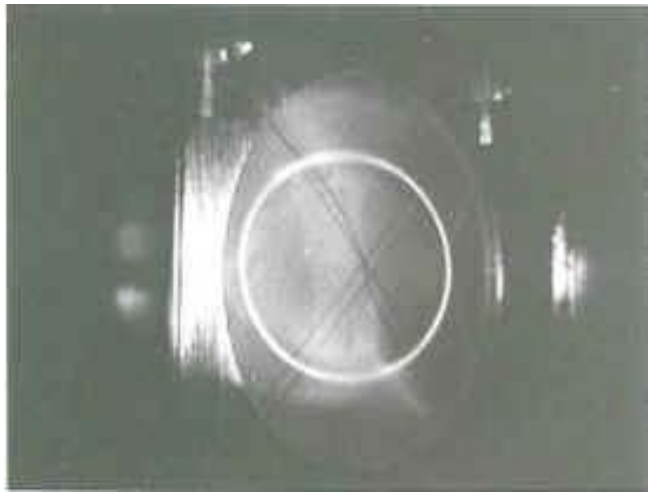



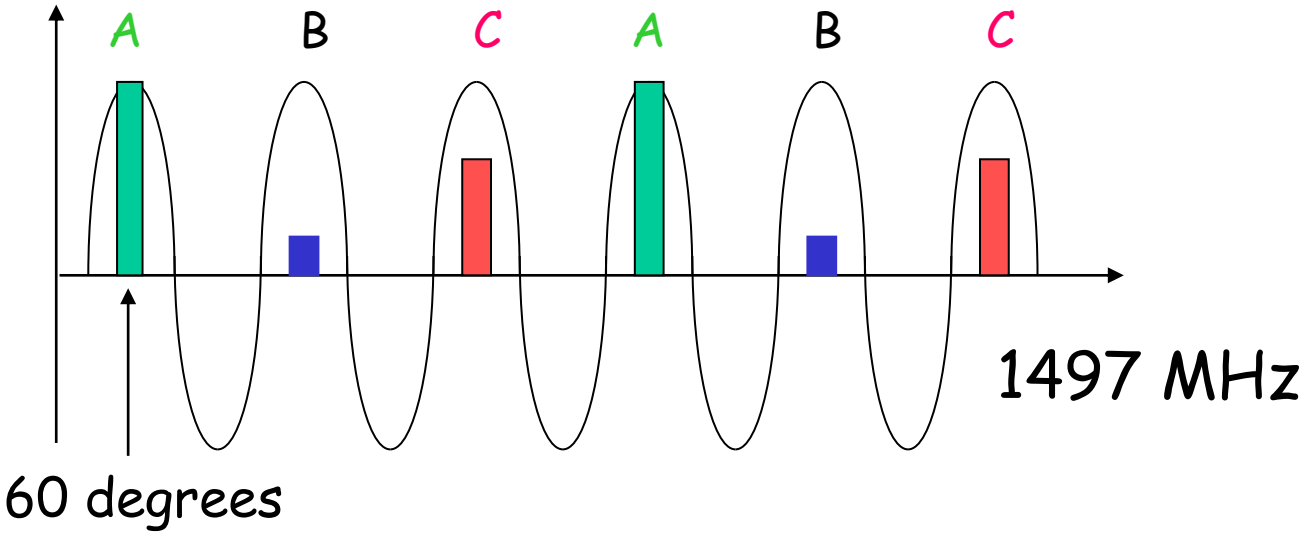
# Photo Finish, but at 2 billionths of a second !!!

3 lasers pulsing

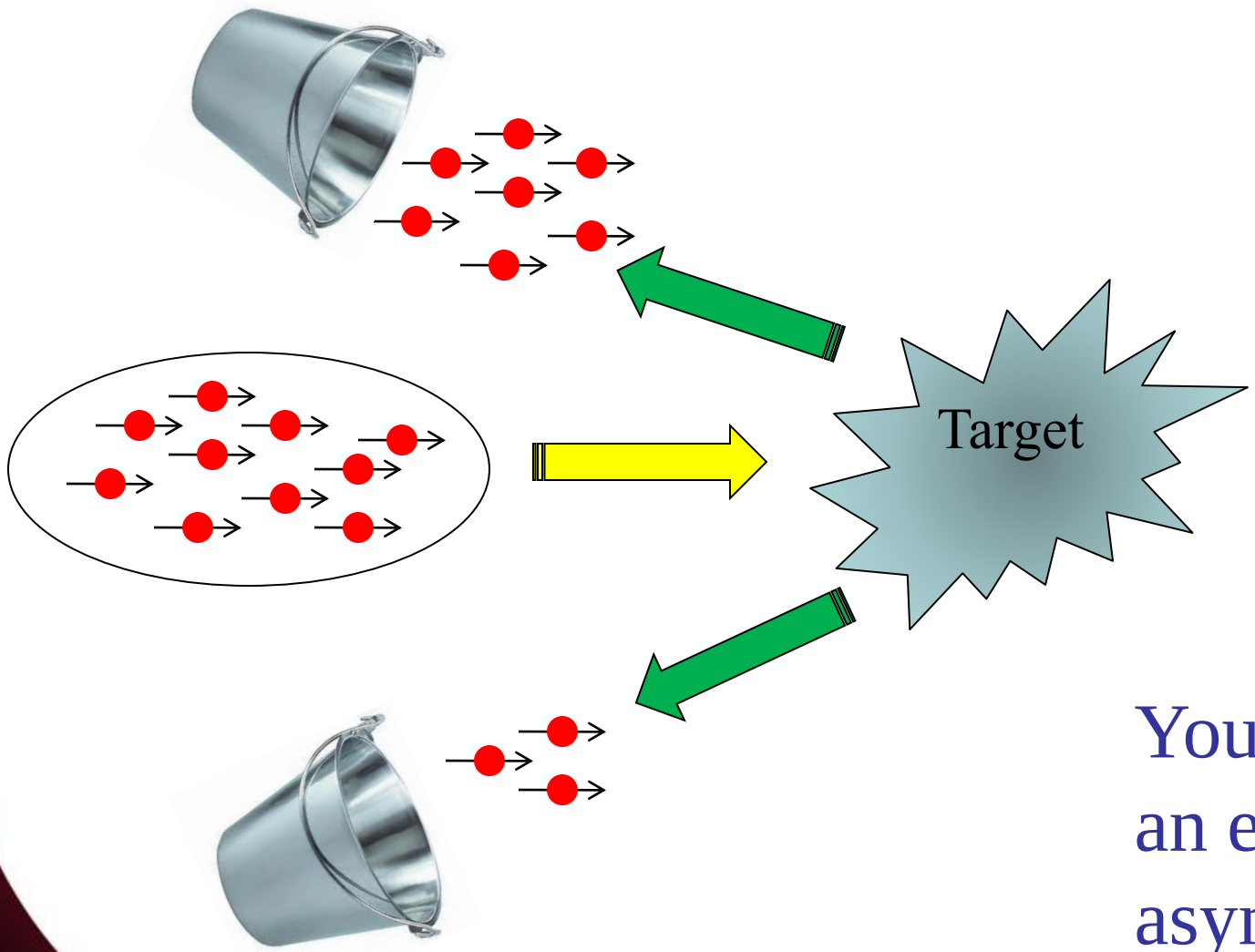



DC beam, not so useful





# What about the probing with spin ?

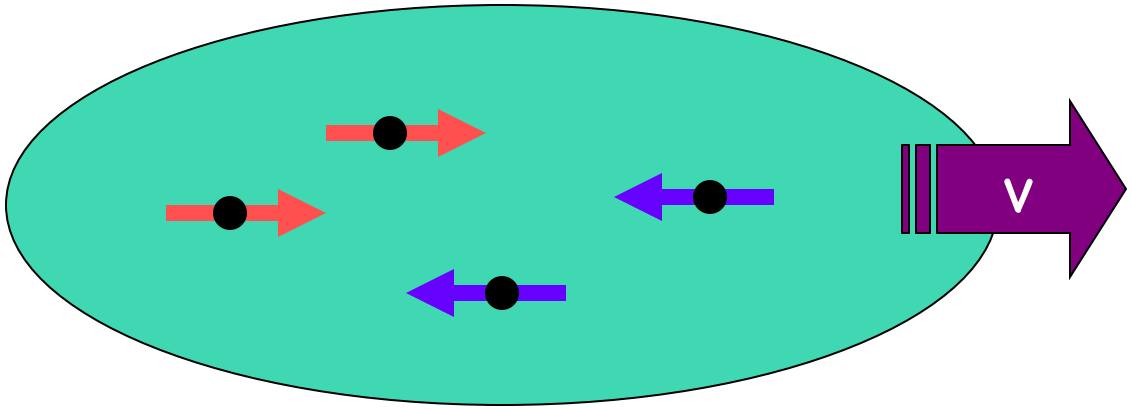



You measure an experimental asymmetry

# Electron Bunch Spin & Polarization

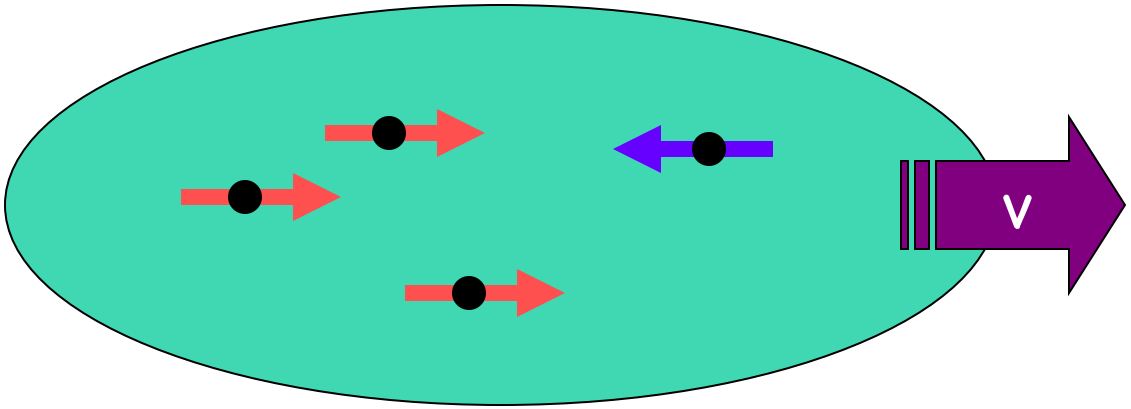
0% Polarization

☹




50% Polarization

☺

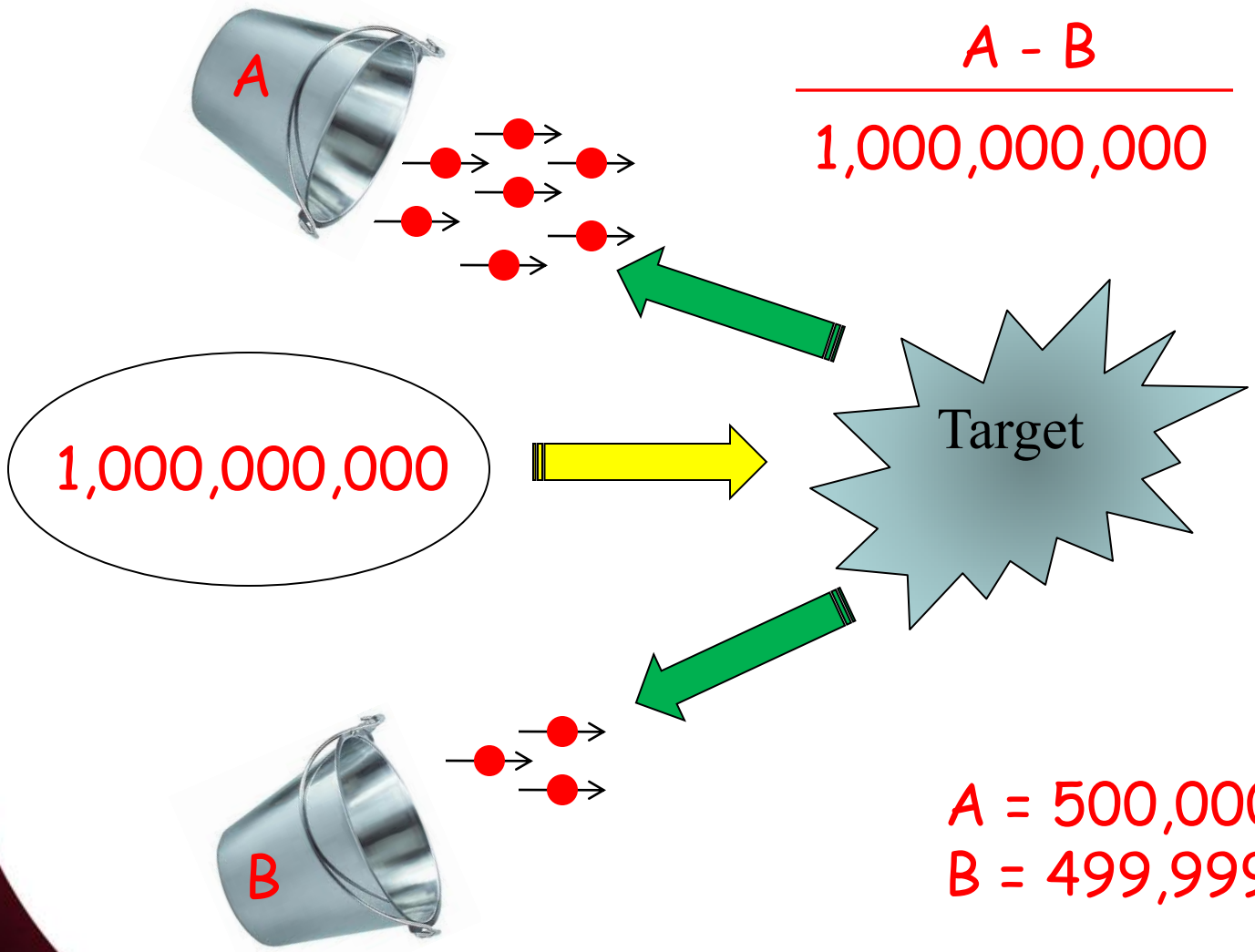


# Parity Violation Experiments at CEBAF

| Experiment | Energy (GeV) | I (μA) | Target | $A_{pv}$ (ppb) | Maximum Charge Asym (ppb) | Maximum Position Diff (nm) | Maximum Angle Diff (nrad) | Maximum Size Diff (δσ/σ) |
|---|---|---|---|---|---|---|---|---|
| **HAPPEx-II (Achieved)** | 3.0 | 55 | $^{1}$H (20 cm) | 1400 | 400 | 1 | 0.2 | Was not specified |
| **HAPPEx-III (Achieved)** | 3.484 | 100 | $^{1}$H (25 cm) | 16900 | 200±100 | 3±3 | 0.5±0.1 | $10^{-3}$ |
| **PREx** | 1.063 | 70 | $^{208}$Pb (0.5 mm) | 500 | 100±10 | 2±1 | 0.3±0.1 | $10^{-4}$ |
| **QWeak** | 1.162 | 180 | $^{1}$H (35 cm) | 234 | 100±10 | 2±1 | 30±3 | $10^{-4}$ |
| **Møller** | 11.0 | 75 | $^{1}$H (150 cm) | 35.6 | 10±10 | 0.5±0.5 | 0.05±0.05 | $10^{-4}$ |

PV experiments motivate polarized e-source R&D

# What does “234 ppb” even mean?



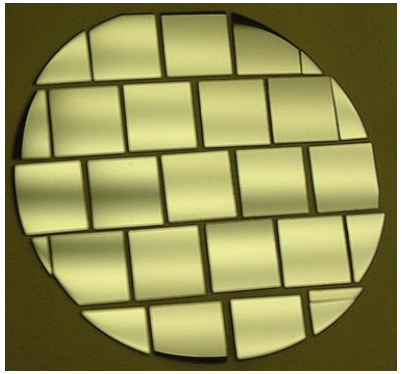

$$\frac{A - B}{1{,}000{,}000{,}000}$$

A = 500,000,117
B = 499,999,883

# Polarized Electron Source "Musts"

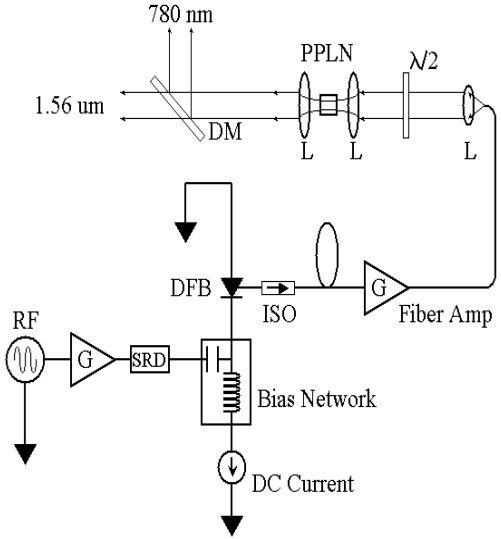
## Good Photocathode

- Many electrons/photon
- High Polarization
- Fast response time



## Good Laser

- Lots of Photons
- CW Pulses
- High Polariztion




## Good Electron Gun

- Accelerate Electrons
- Happy Photocathode
- Integrate Laser

# Photoemission from GaAs

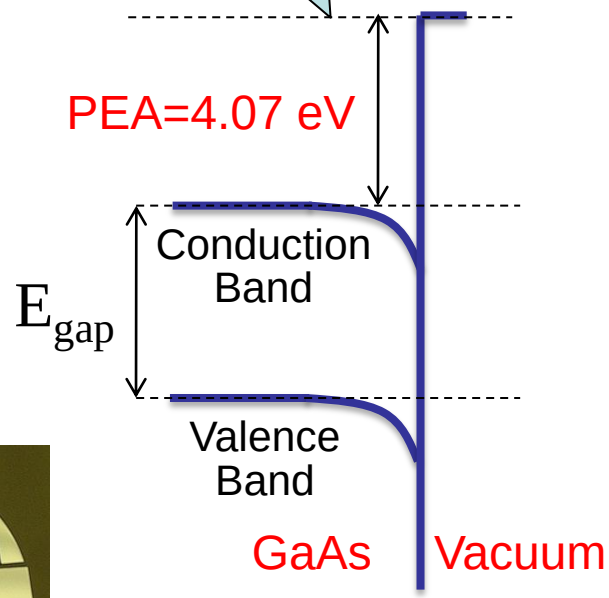
**Bare GaAs surface**

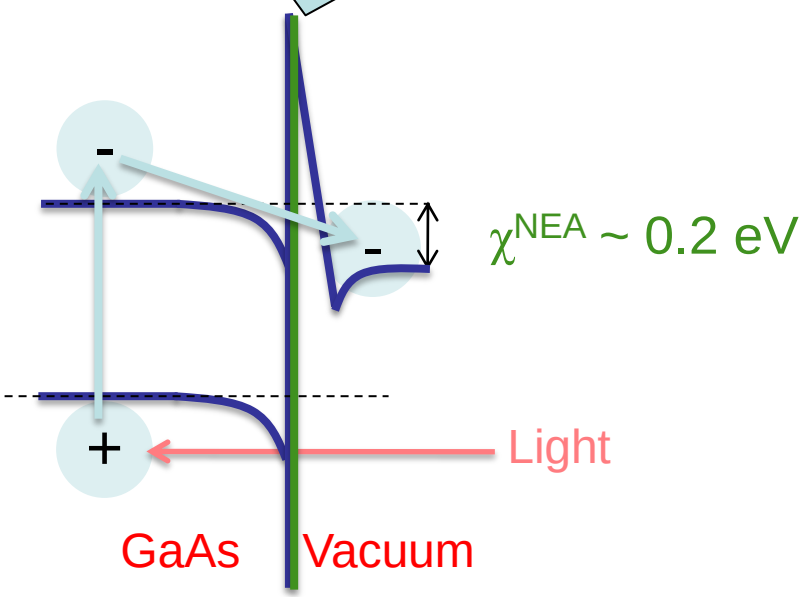
- Large Work Function
- Positive Electron Affinity (PEA)

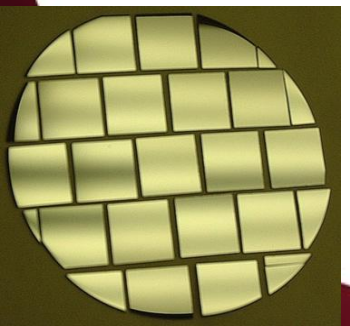
NEA Surface Activation

**Dipole layers of Cesium + $NF_3$**

- Reduces Work Function
- Negative Electron Affinity (NEA)



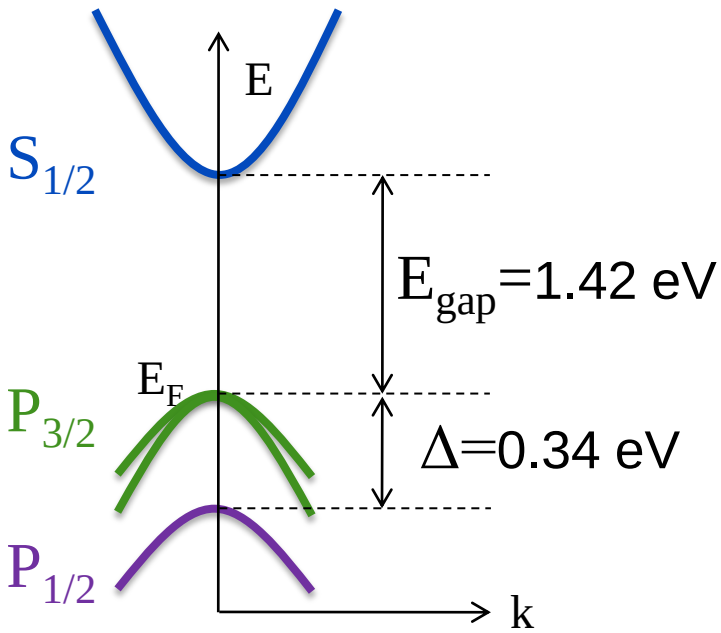



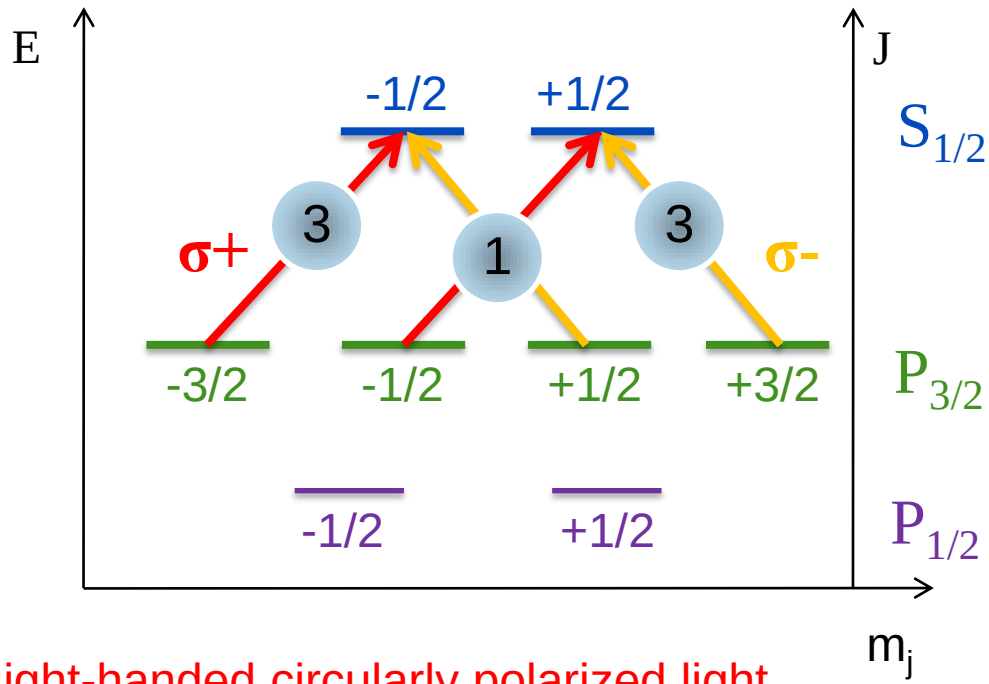



$$\text{Quantum Efficiency} = N_{e-} / N_{\gamma}$$

# Bulk GaAs

- Laser excitation from $P_{3/2}$ to $S_{1/2}$ : $E_{gap} < E_{\gamma} < E_{gap}+\Delta$
- Electron Polarization: $P_e < \frac{3-1}{3+1} = 50\%$




σ+: Right-handed circularly polarized light

σ- : Left-handed circularly polarized light

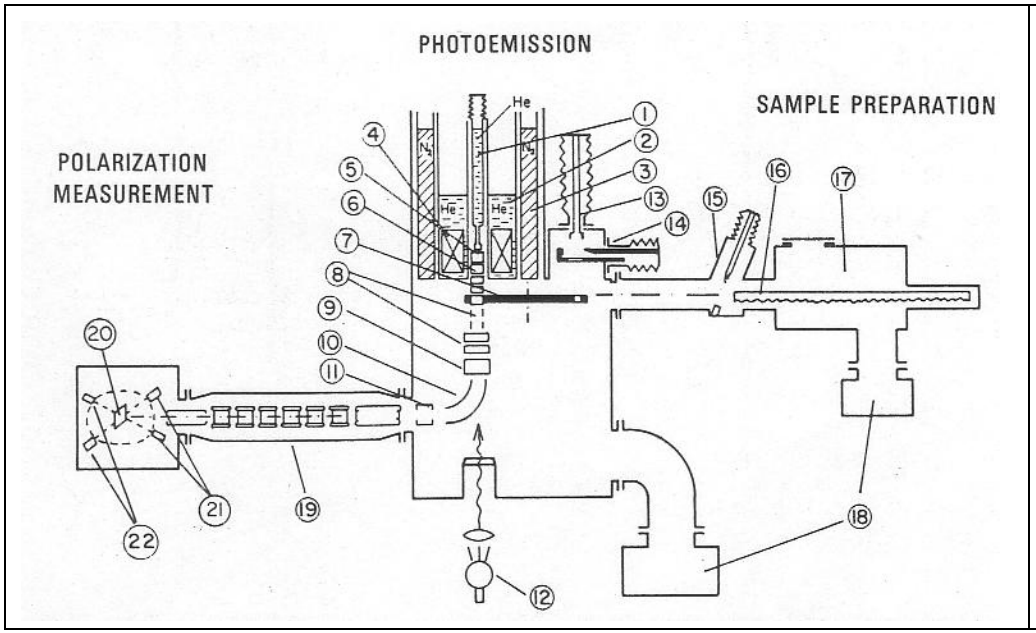
- Reverse electron polarization by reversing light polarization

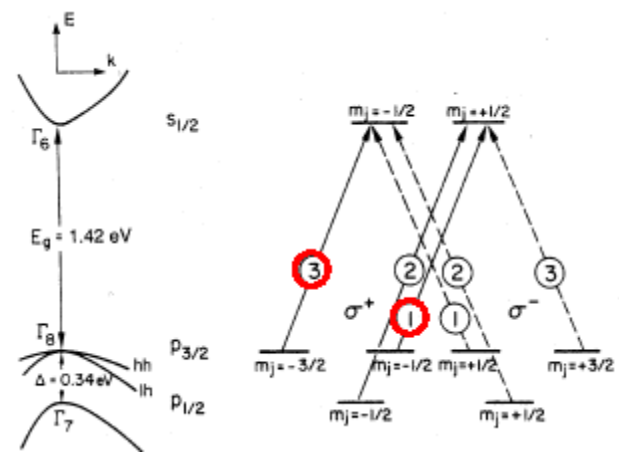
# The First GaAs Photoemission Source

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)



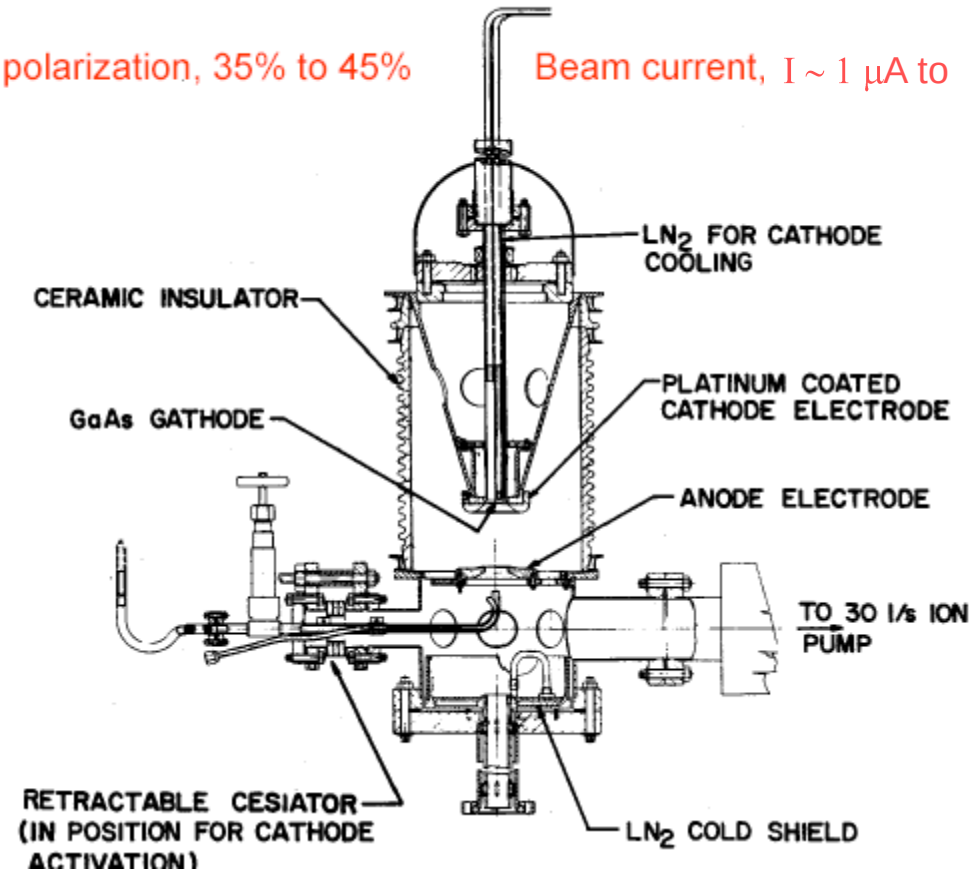

$$P = \frac{3-1}{3+1} = 50\%$$

# 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



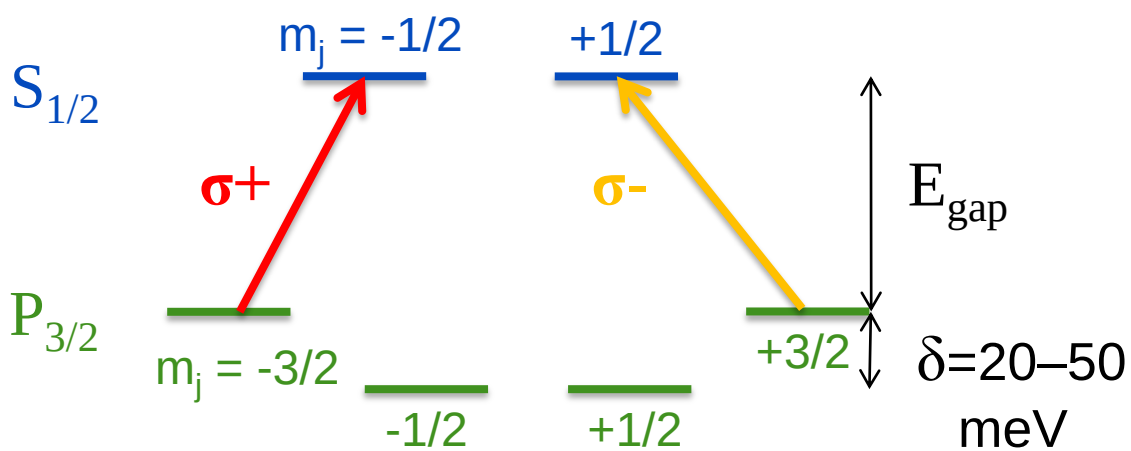

Electrons into the accelerator Dec., 1977

Collaboration announces parity violation June, 1978

# Higher P: Breaking GaAs Degeneracy

- Split degeneracy of $P_{3/2}$ : Introduce strain on GaAs crystal by growing it on substrate (GaAsP) with different lattice constant

- High polarization by laser excitation from $P_{3/2}$ to $S_{1/2}$ :
  $E_{gap} < E_{\gamma} < E_{gap}+\delta$



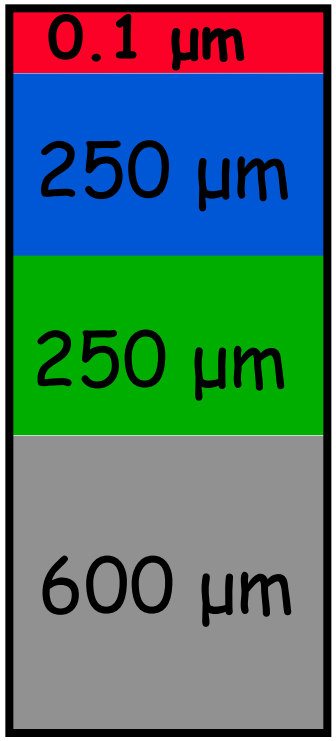

- Higher QE: Alternating layers of GaAs and GaAsP – **Superlattice GaAs**

# Strained layer GaAs

## Bandwidth Semiconductor (formerly *SPIRE*)

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

$\Rightarrow$ 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

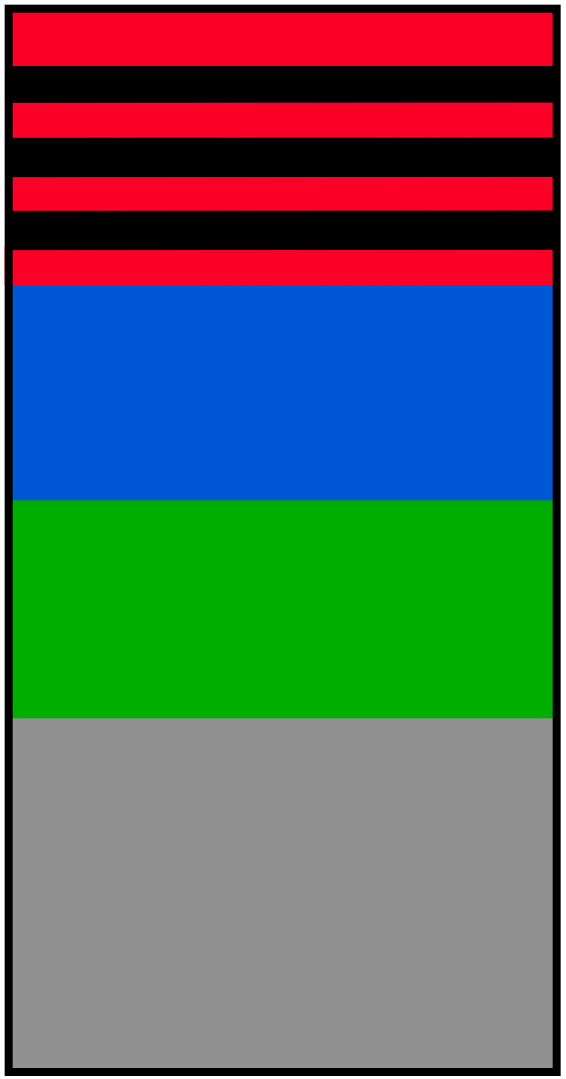
# Strained Layer - Superlattice GaAs

Be doping ($cm^{-3}$)

$5.10^{19}$

$5.10^{17}$

$5.10^{18}$



GaAs (5 nm)

GaAsP (3 nm)
GaAs (4 nm)
14 pairs

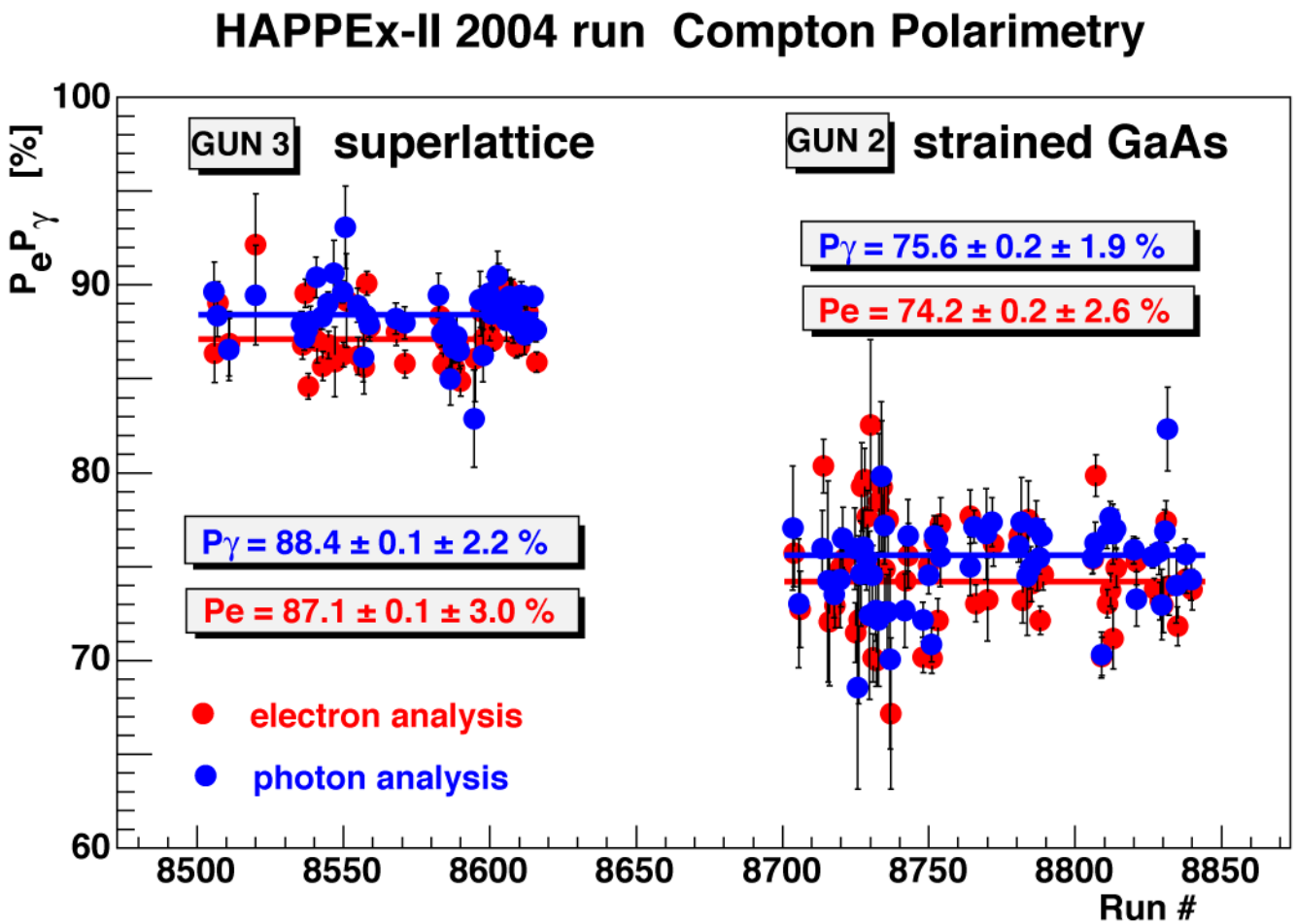
$GaAs_{0.64}P_{0.36}$ (2.5 µm)

$GaAs_{1-x}P_x$ , $0<x<0.36$ (2.5 µm)

p-type GaAs substrate

*SVT associates, per SLAC specs.*

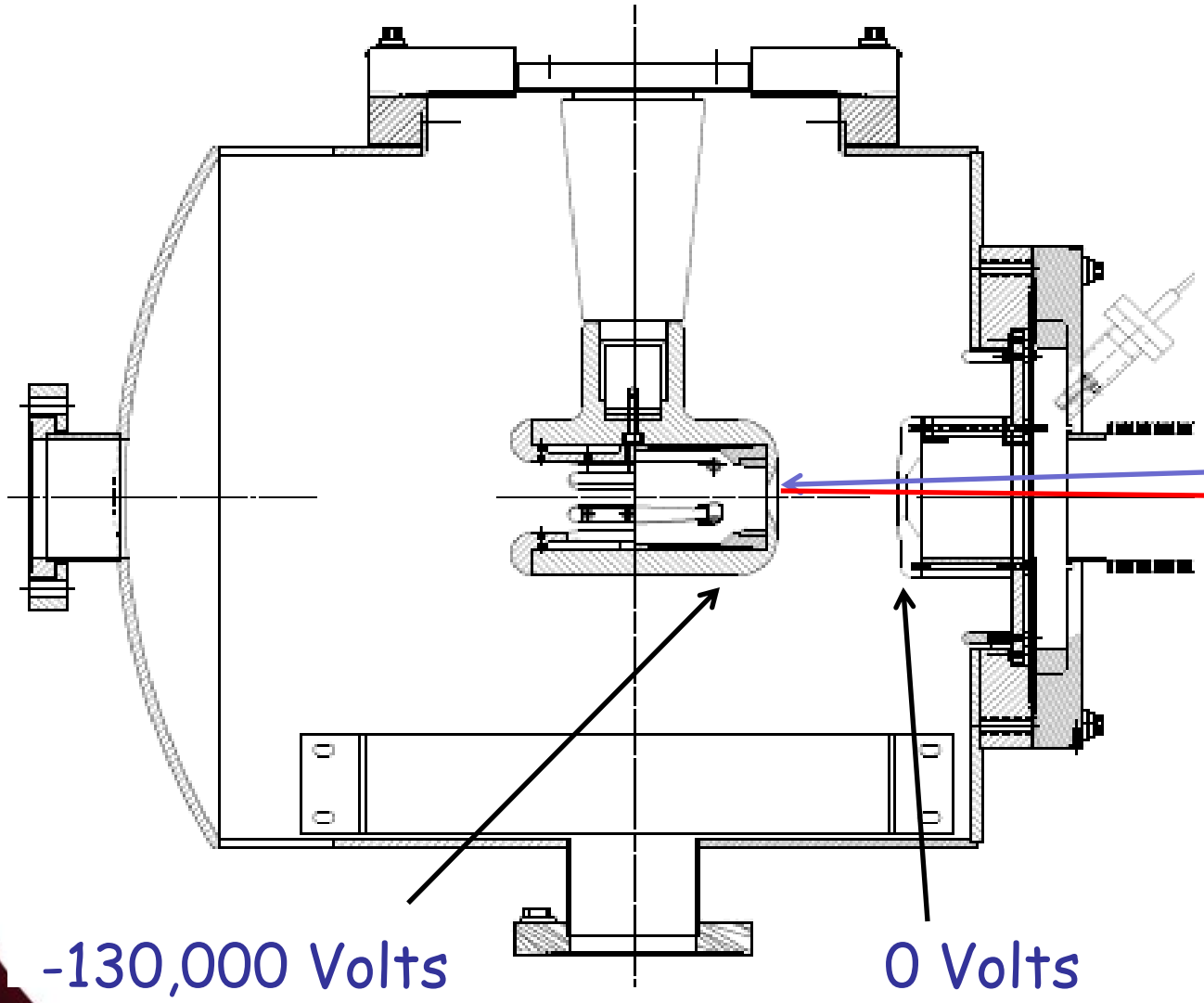
# And, it really works!




Experiment Figure of Merit

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

# Electron Gun Cut-Away




Laser shines on GaAs & frees the electrons…

…the -130kV "battery" accelerates and forms the electron beam.

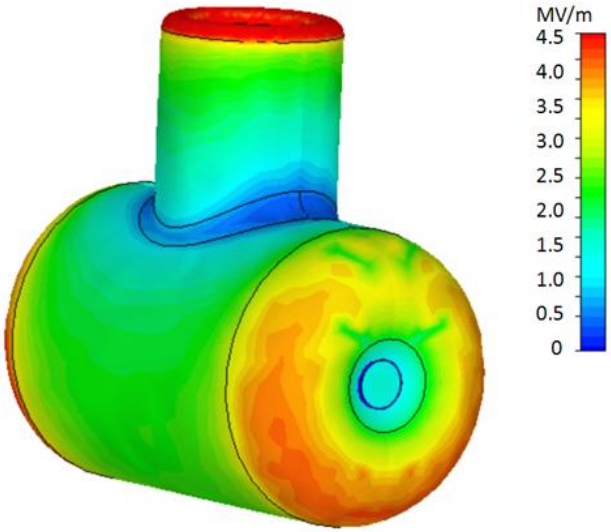
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 010101 (2010)

## Load-locked dc high voltage GaAs photogun with an inverted-geometry ceramic insulator

P. A. Adderley, J. Clark, J. Grames, J. Hansknecht, K. Surles-Law, D. Machie, M. Poelker,*
M. L. Stutzman, and R. Suleiman

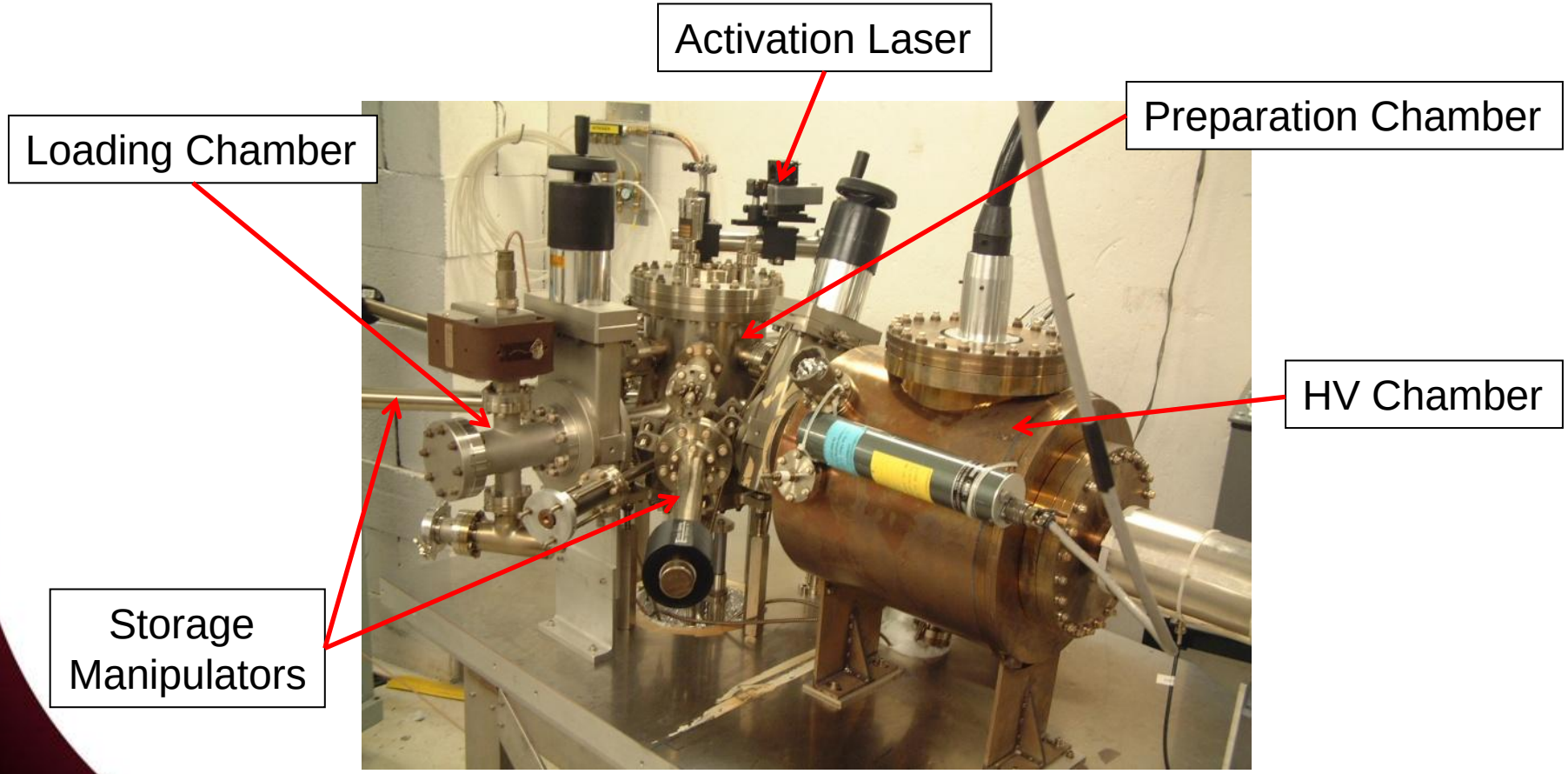
*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA*
(Received 24 November 2009; published 26 January 2010)

A new dc high voltage spin-polarized photoelectron gun has been constructed that employs a compact inverted-geometry ceramic insulator. Photogun performance at 100 kV bias voltage is summarized.

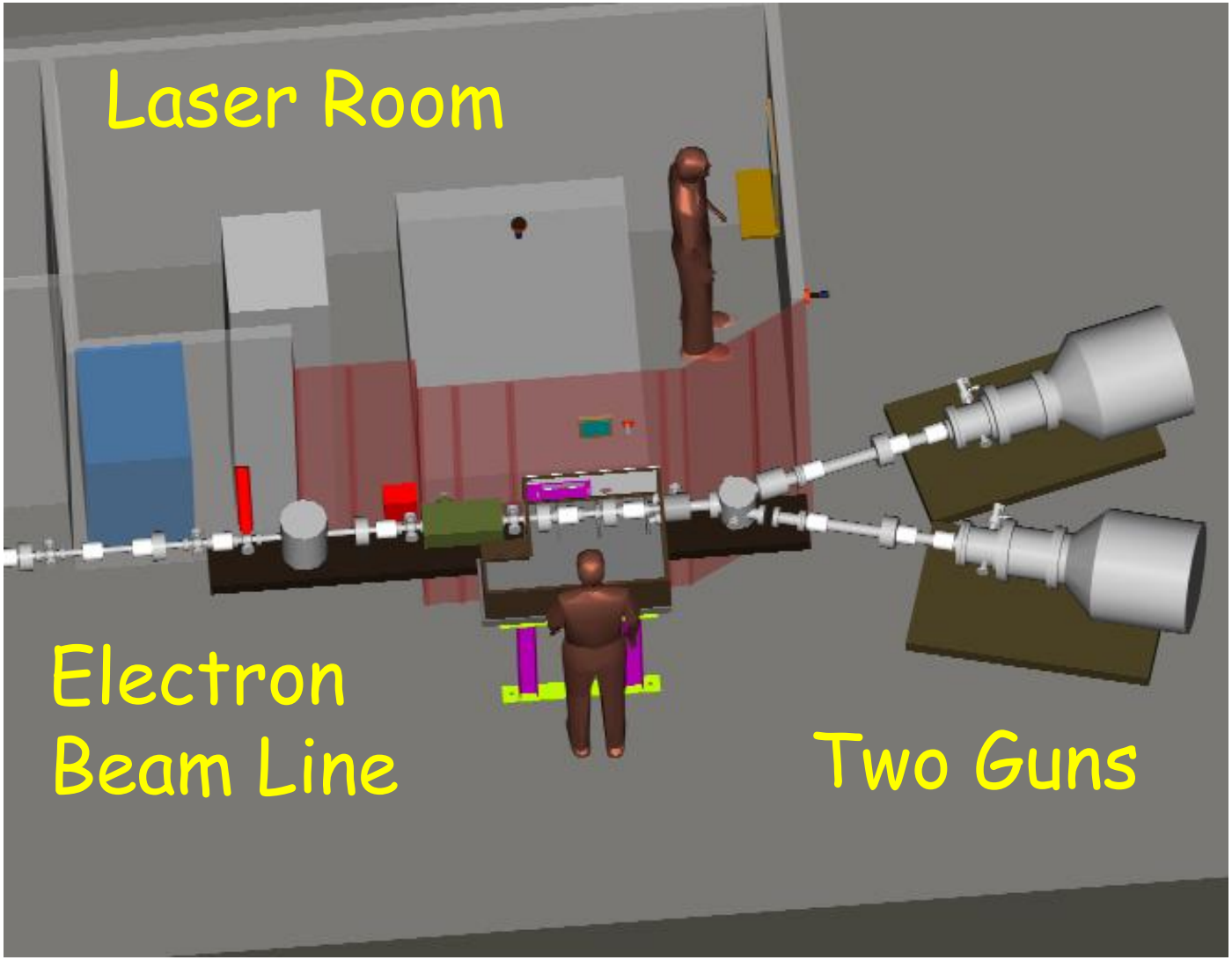


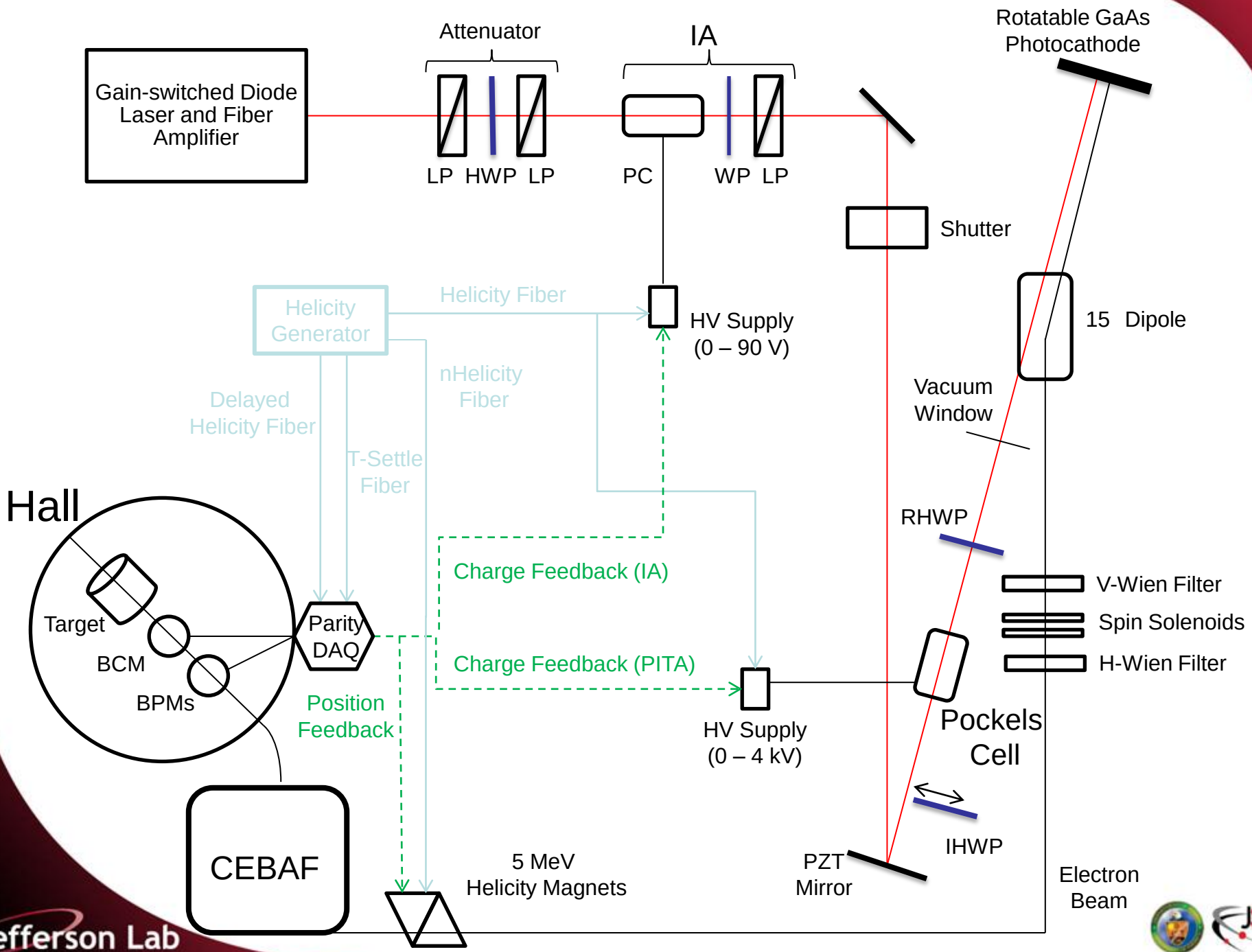
# Load-lock Photogun

- Best vacuum inside HV Chamber, which is never vented except to change electrodes
- Photocathode Heat and Activation takes place inside Preparation Chamber
- Use “Suitcase” to replace photocathodes through a Loading Chamber

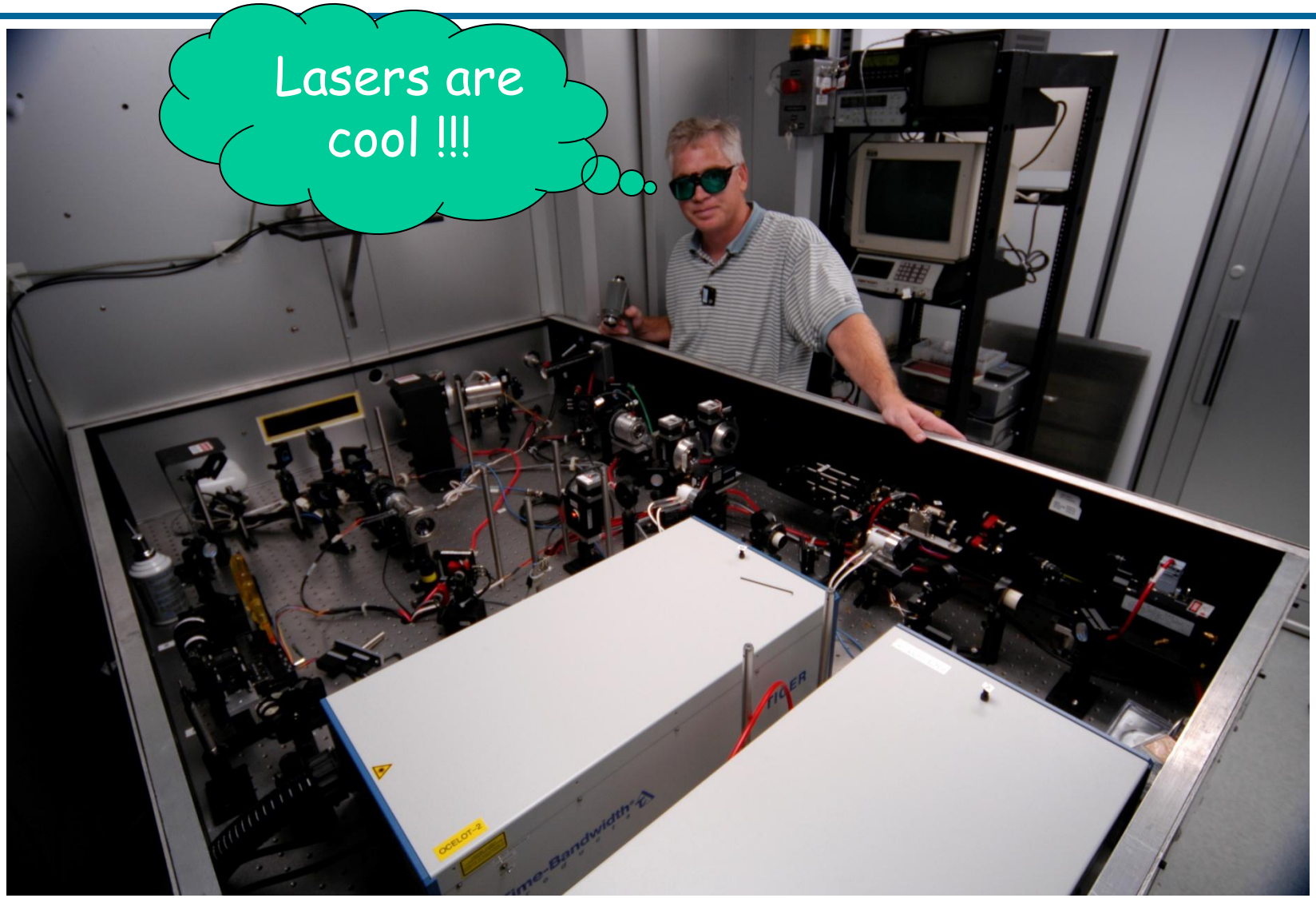


# Bird's Eye View



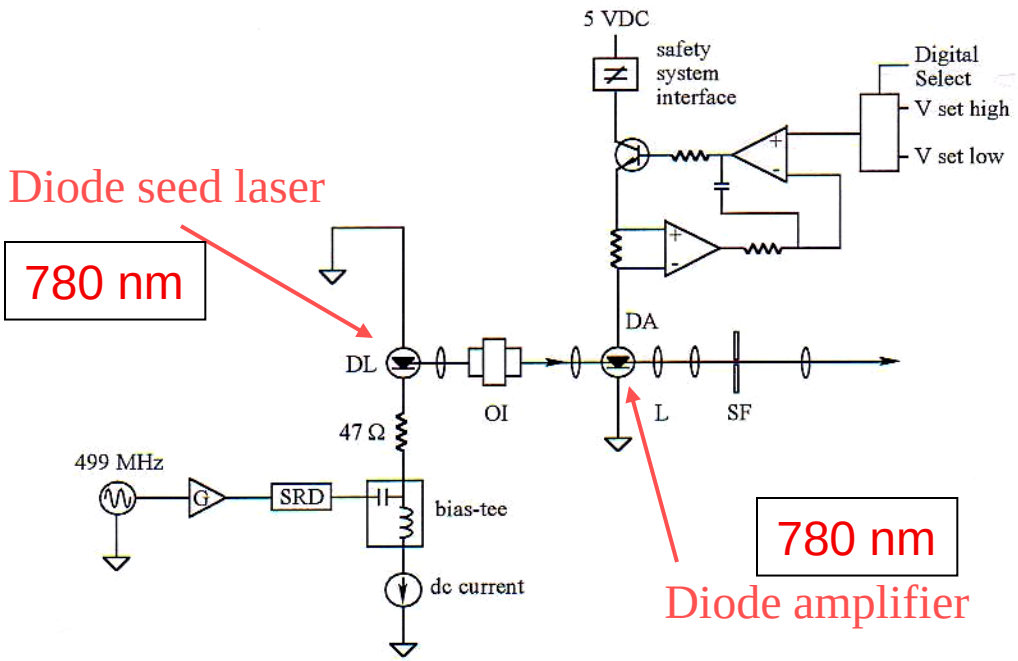

Gain-switched Diode Laser and Fiber Amplifier
Attenuator
LP HWP LP
IA
PC
WP LP
Rotatable GaAs Photocathode
Shutter
Helicity Generator
Helicity Fiber
HV Supply (0 – 90 V)
15 Dipole
Vacuum Window
Delayed Helicity Fiber
nHelicity Fiber
T-Settle Fiber
Hall
Target
BCM
BPMs
Parity DAQ
Charge Feedback (IA)
Charge Feedback (PITA)
Position Feedback
RHWP
V-Wien Filter
Spin Solenoids
H-Wien Filter
HV Supply (0 – 4 kV)
Pockels Cell
IHWP
CEBAF
5 MeV Helicity Magnets
PZT Mirror
Electron Beam
Jefferson Lab
JSA

# Laser Room for Dust & Climate Control

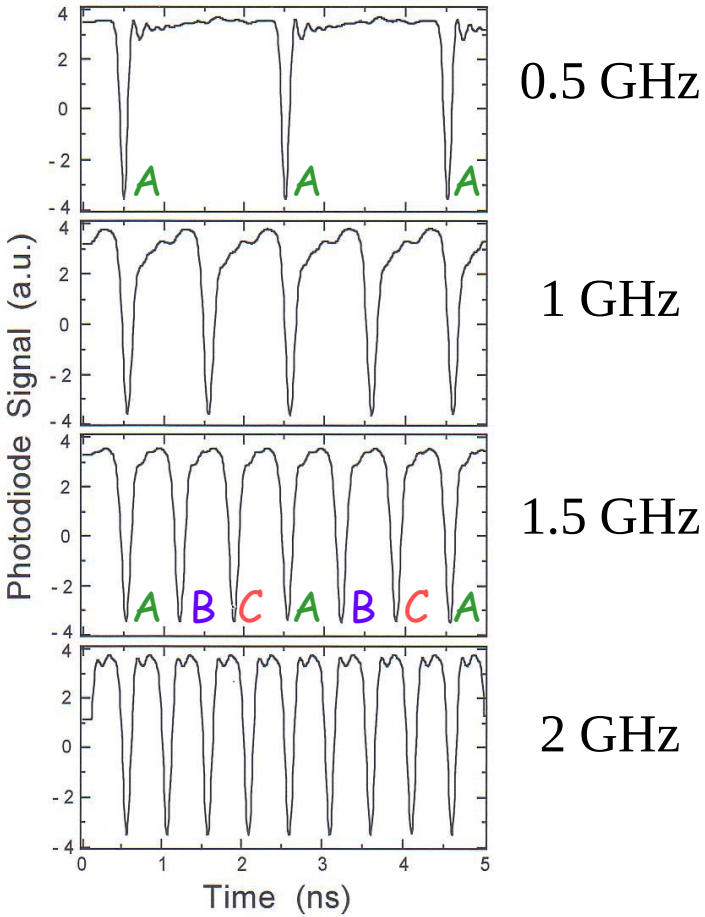


# Radio Frequency Pulsed Lasers

## RF Gain Switching

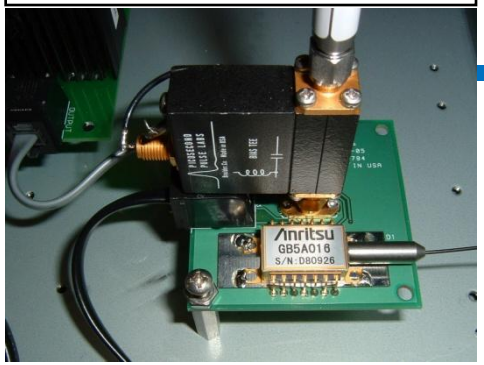


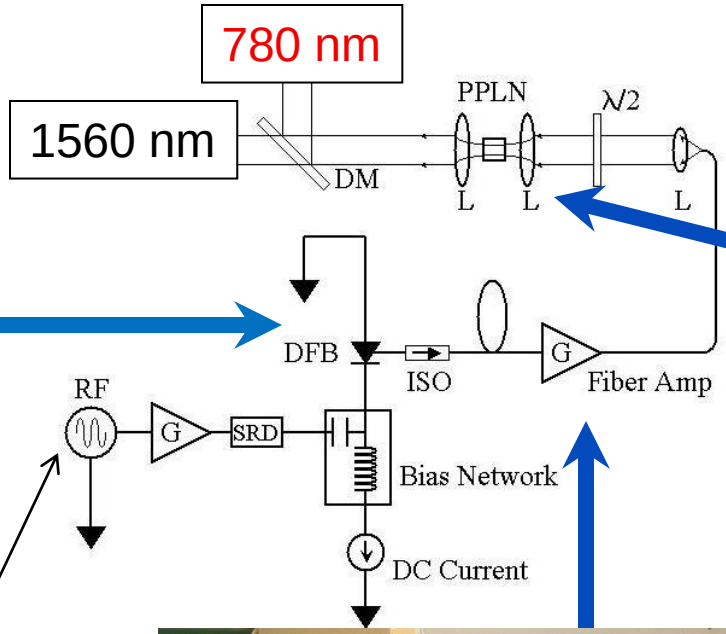

M. Poelker, Appl. Phys. Lett. **67**, 2762 (1995).



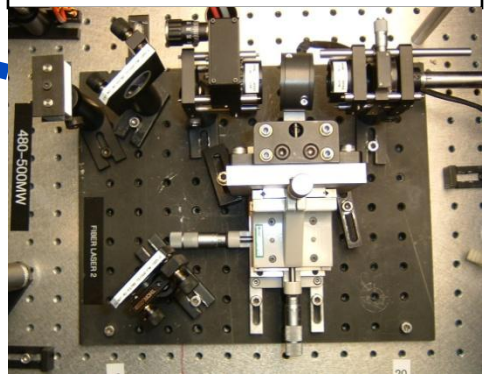
# Fiber-based Drive Laser

RF Locked Low-Power
(1 mW)
1560 nm Fiber Diode

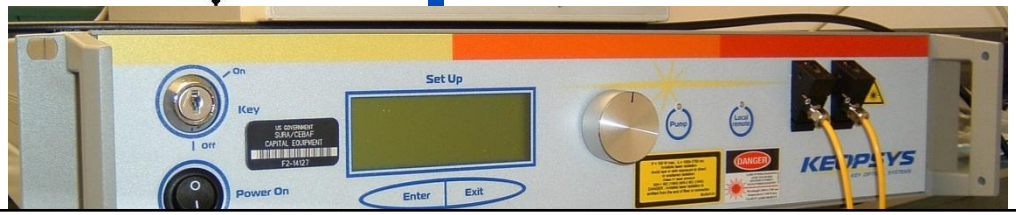



Frequency-doubler
1560 nm to 780 nm
30% Efficiency (2 W)



499 MHz




High Power (6 W) 1560 nm Fiber Amplifier

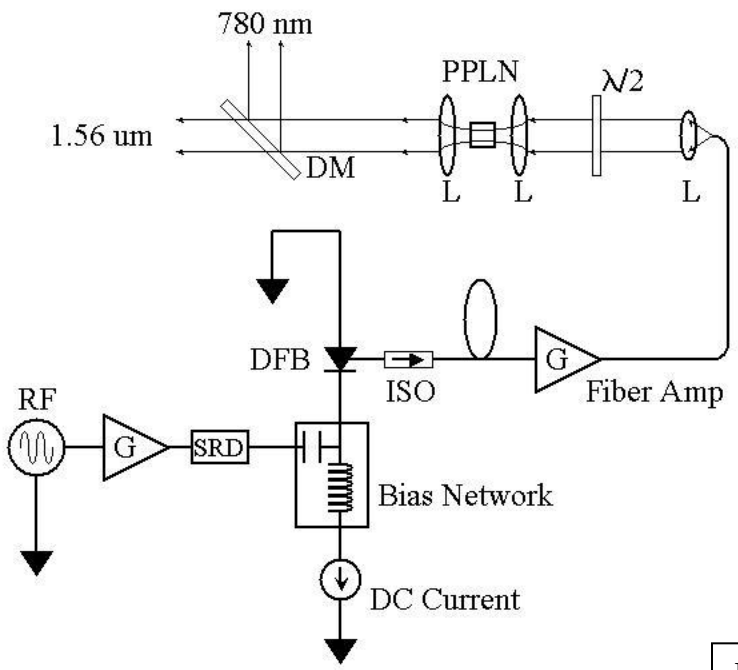
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 9, 063501 (2006)

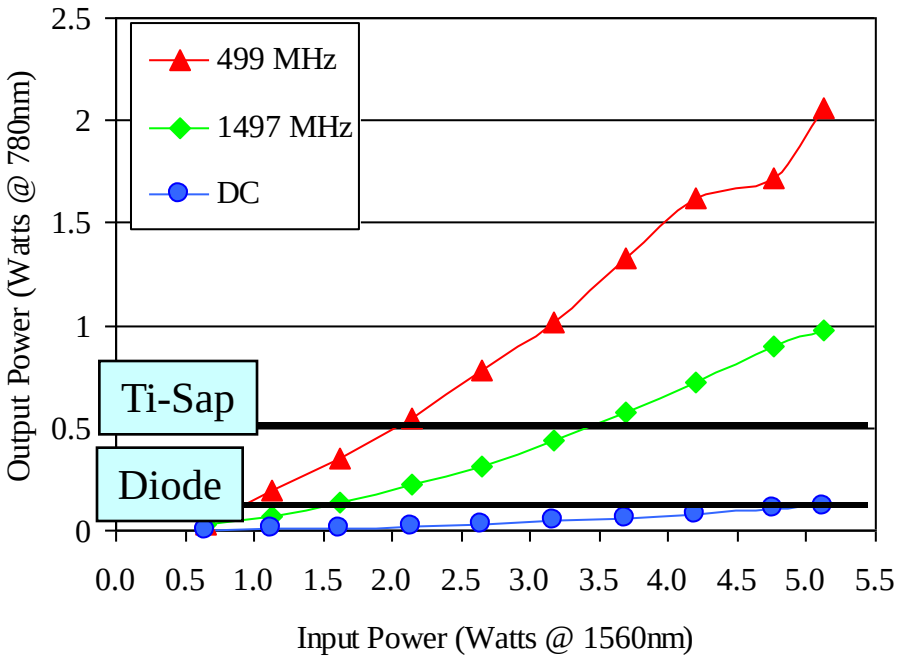
**Synchronous photoinjection using a frequency-doubled gain-switched fiber-coupled seed laser and ErYb-doped fiber amplifier**

J. Hansknecht* and M. Poelker
*Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, Virginia 23606, USA*
(Received 12 April 2006; published 21 June 2006)

Light at 1560 nm from a gain-switched fiber-coupled diode laser and ErYb-doped fiber amplifier was frequency doubled to obtain over 2 W average power at 780 nm with ~40 ps pulses and pulse repetition rate of 499 MHz. This light was used to drive the 100 kV DC high voltage GaAs photoemission gun at the

# New Fiber-Based Drive Laser

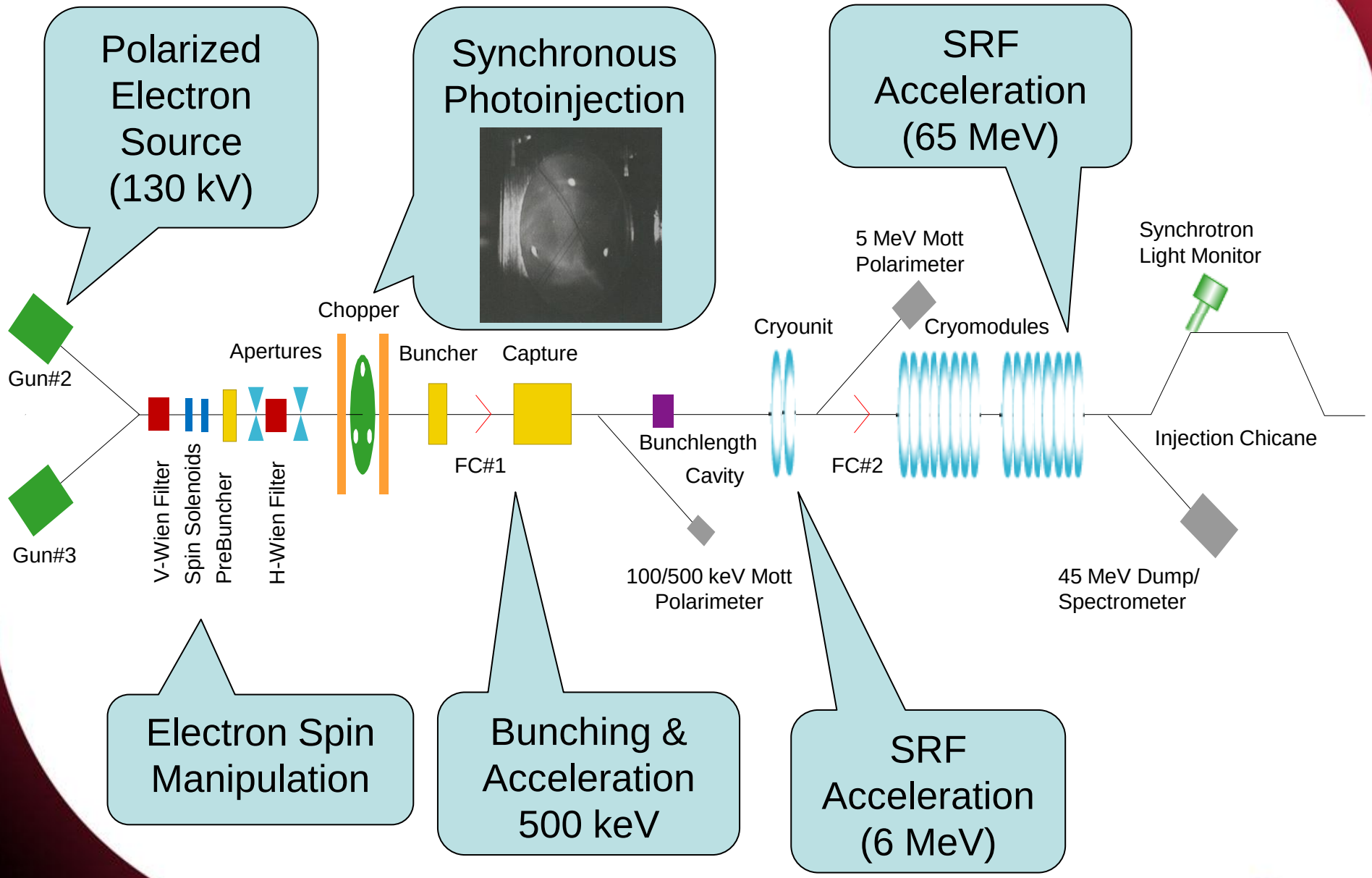


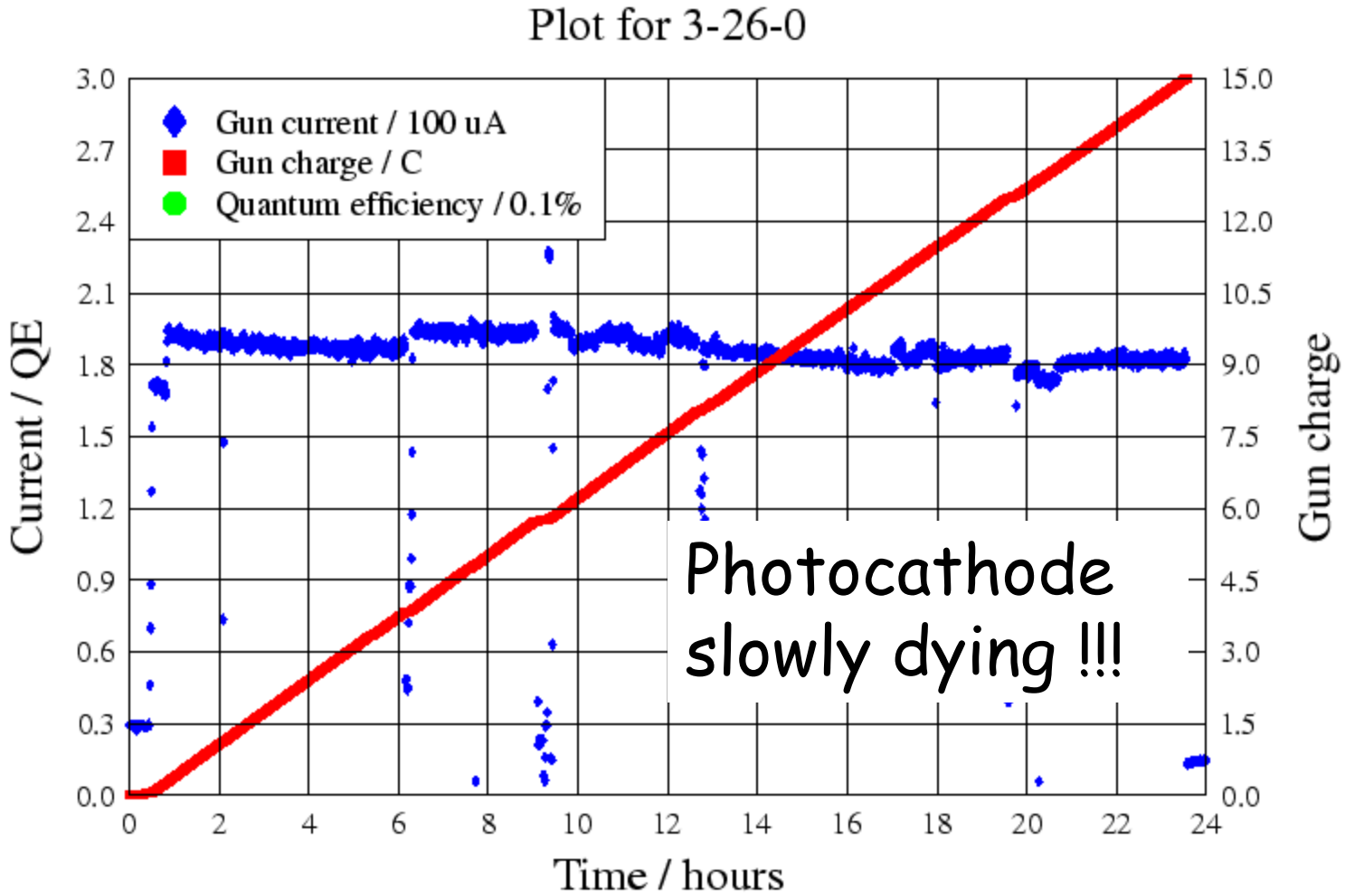

J. Hansknecht and M. Poelker, Phys. Rev. ST Accel. Beams 9, 063501 (2006)

- 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)

# Polarized Electron Injector

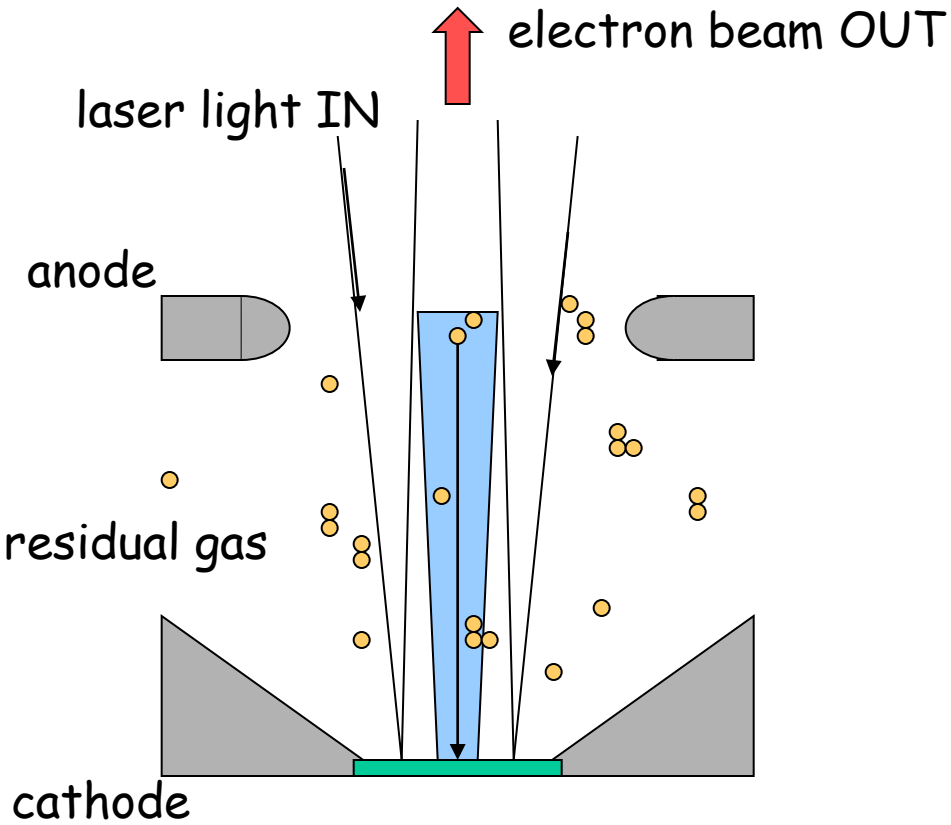


# Who wants polarized electrons?

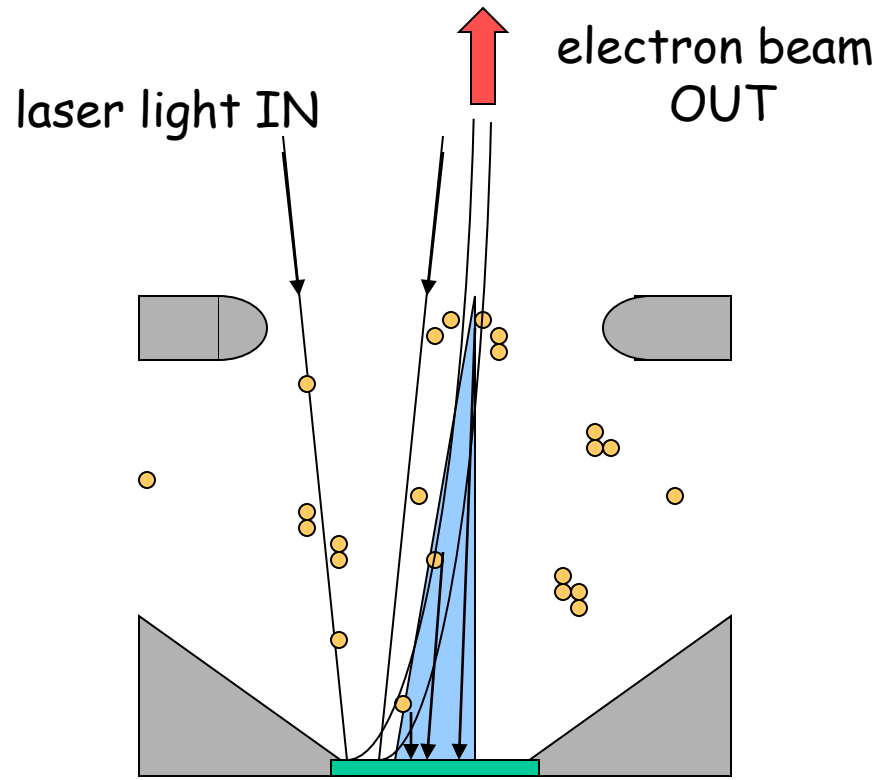


# Ion Back-Bombardment

High energy ions focused to electrostatic center



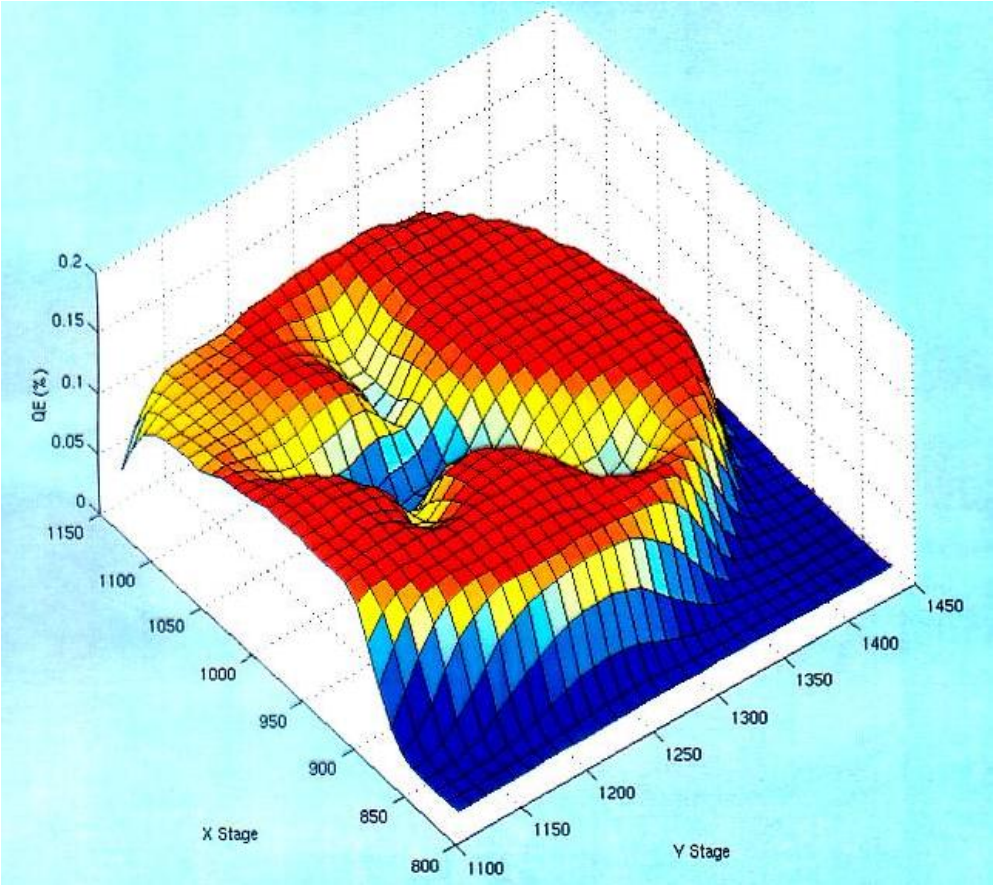

We don't run beam from electrostatic center

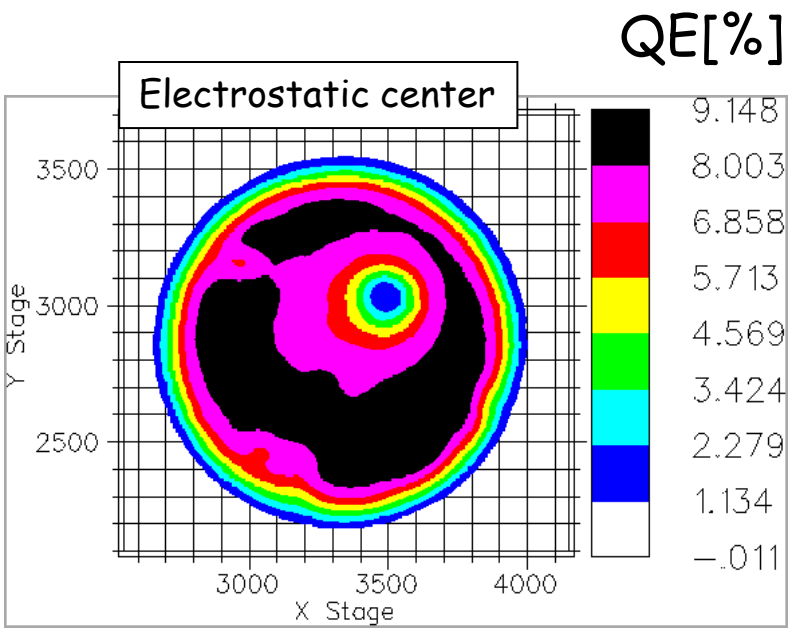



Ions create QE trough to electrostatic center

# Bad, bad ions…

Imperfect vacuum => QE degrades via ion backbombardment



# Vacuum regimes

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

- 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

# 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 |

# 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" – Gary Larson

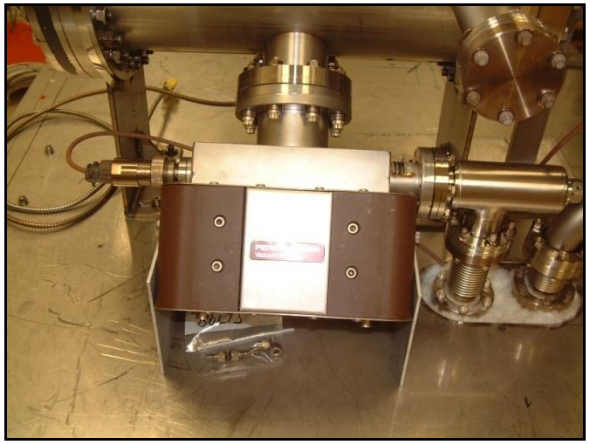
# Where does the gas come from?

- **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

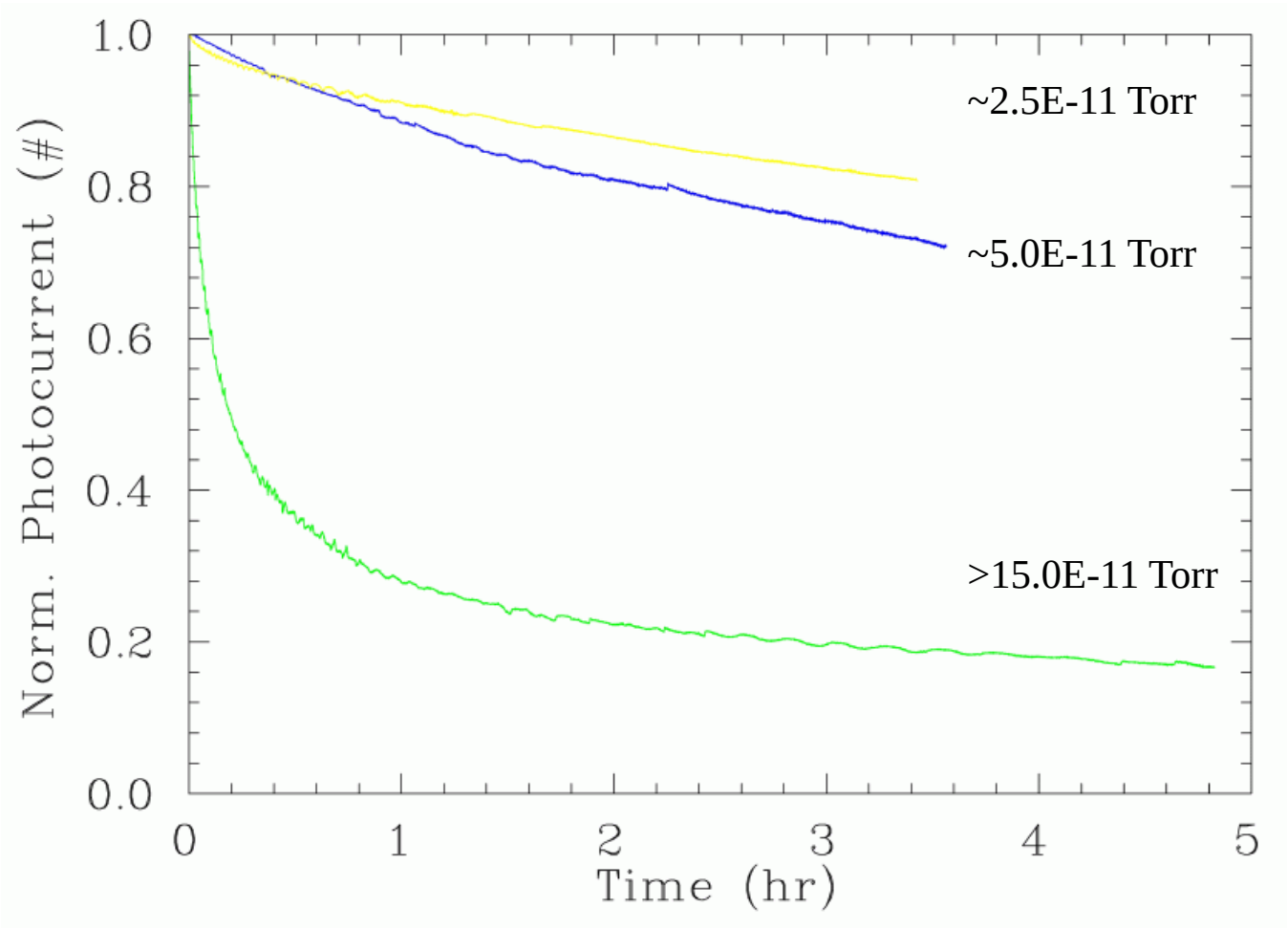
- **Getter Pumps**
  - Chemically active surface
    - Titanium sublimed from hot filament
    - Non-Evaporative Getters
  - Molecules stick when they hit
    - Does not work well for inert gasses such as Argon, Helium or for methane
- **Ion Pumps**
  - Electric field to ionize gasses
  - Magnetic field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



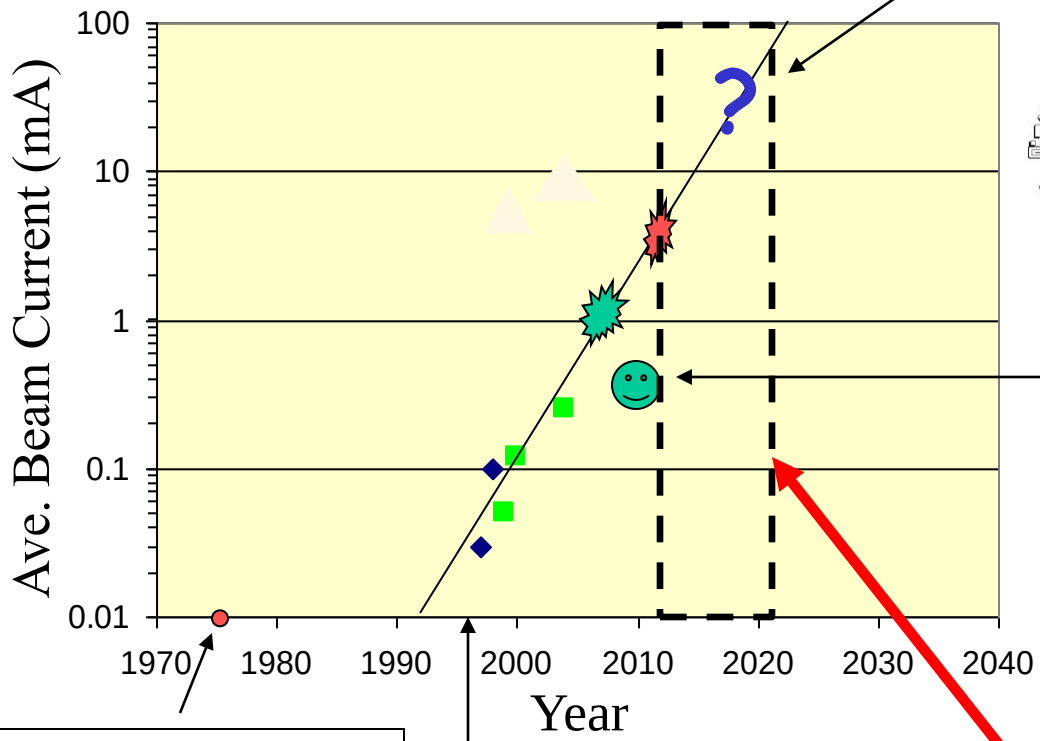
**Ion Pump**

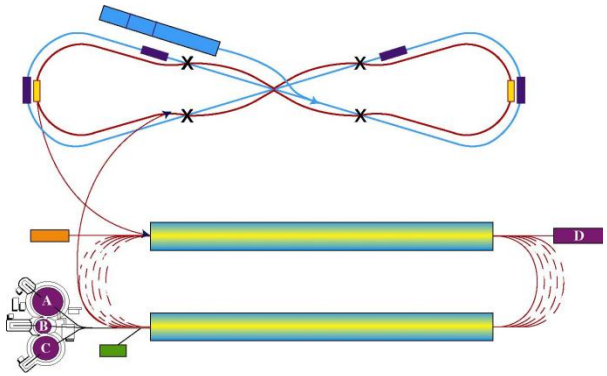
# Better Vacuum = Longer Lifetime

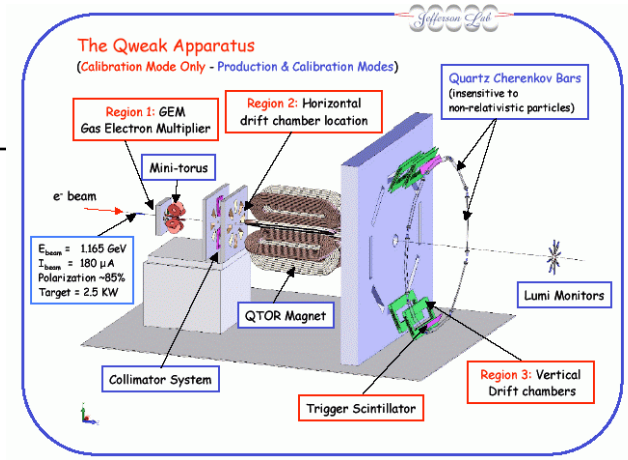



Better Vacuum

# High Polarization from GaAs: Trending toward higher current…






First polarized beam from GaAs photogun

First low polarization, then high polarization at CEBAF

***(Insert your name)* breaks world record !!!**