CEBAF
Polarized Electron Source

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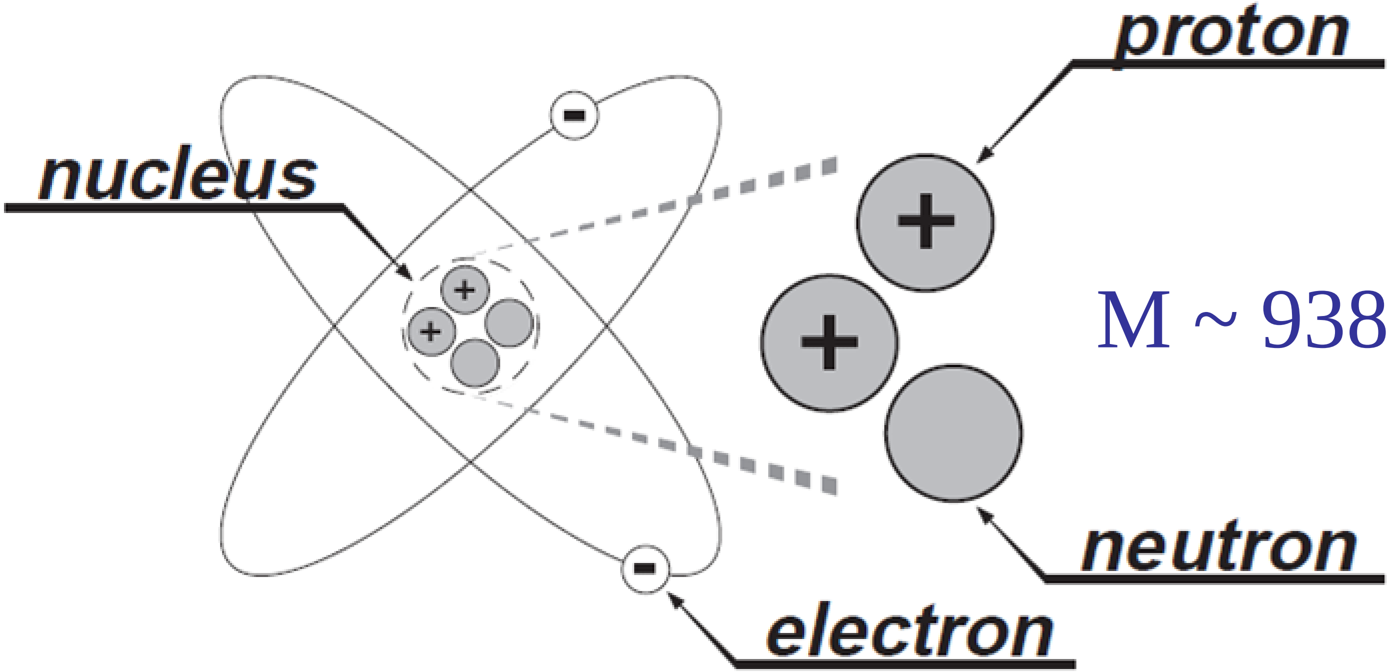
Riad Suleiman, John Hansknecht, Marcy Stutzman, Joe Grames

JLAB Summer Lecture Series, July 17th 2012

How do we "see" what we measure…?



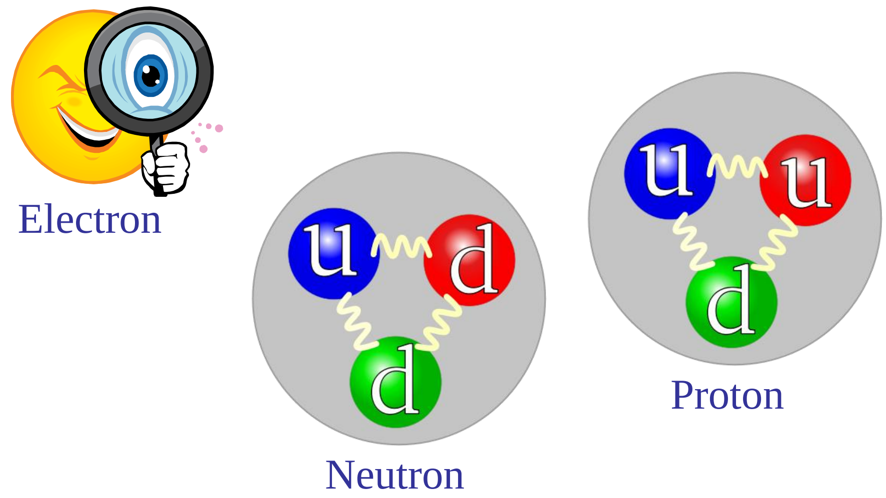
M ~ 938 MeV/c^2

M ~ 0.511 MeV/c^2

mass ~ 1/λ ~ energy

What to do?

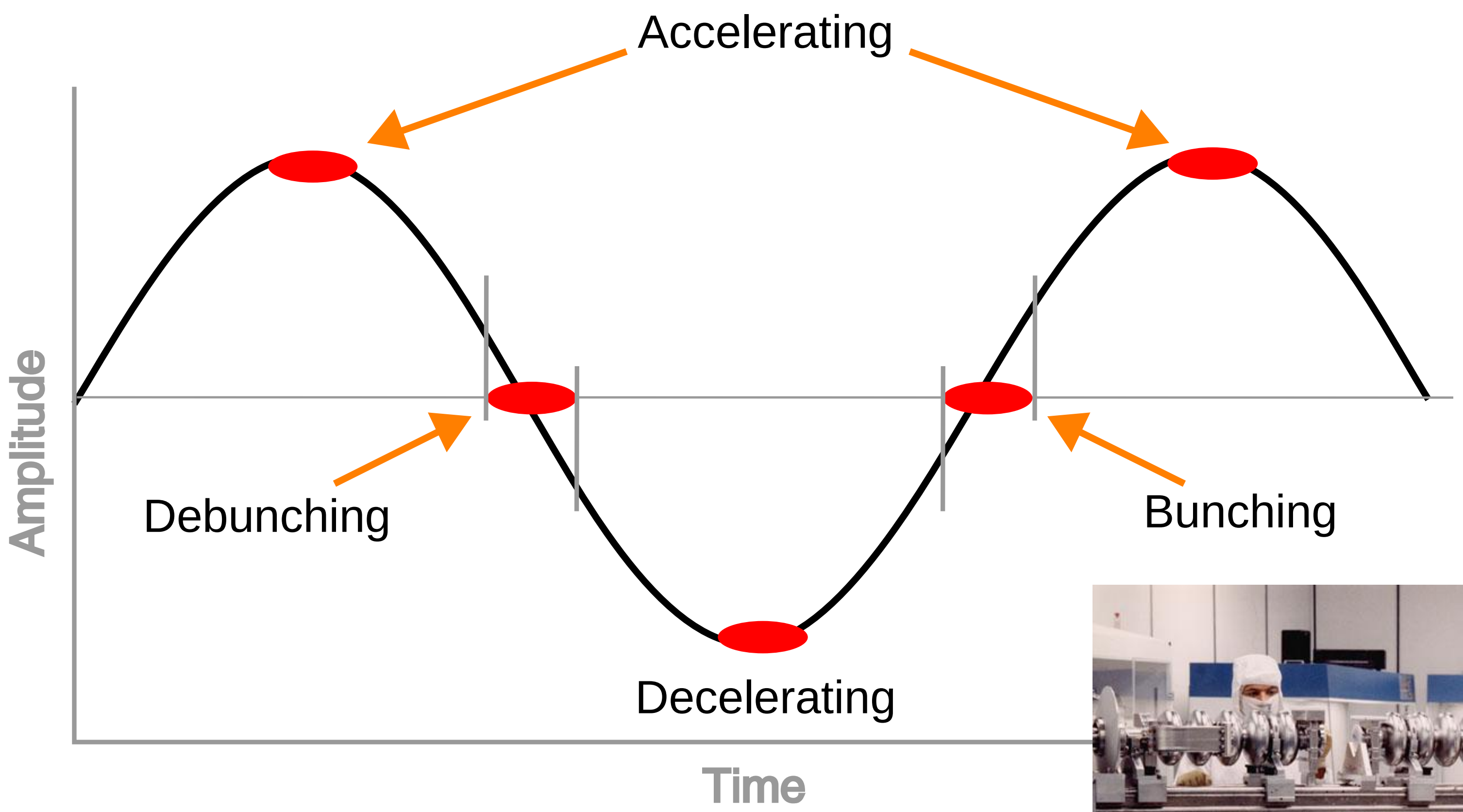
Build a 5 mile long electron microscope!



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

How to make the electrons "powerful" ?

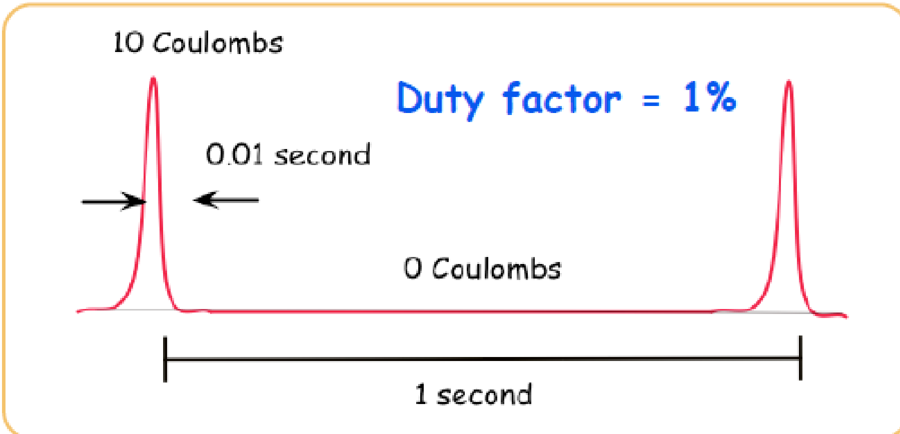
Use radio(frequency) waves !!!



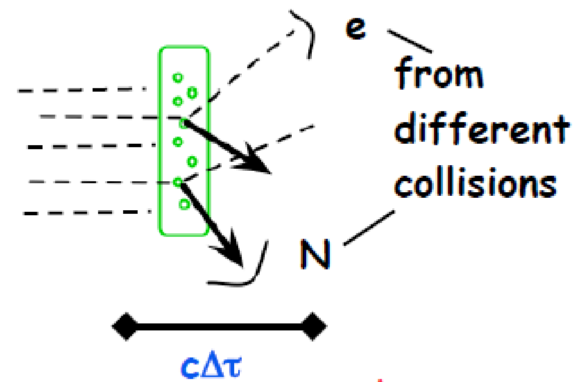
Electrons gain energy on each crest!

The “C” in CEBAF

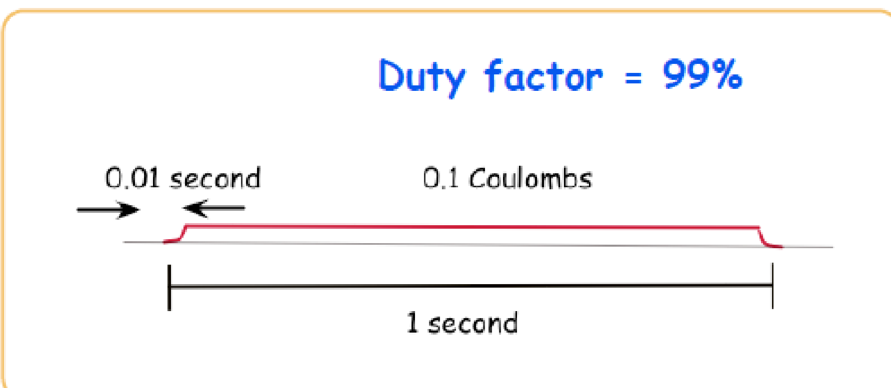
- ★ Pulsed beams used prior to 1980 (100 mA)



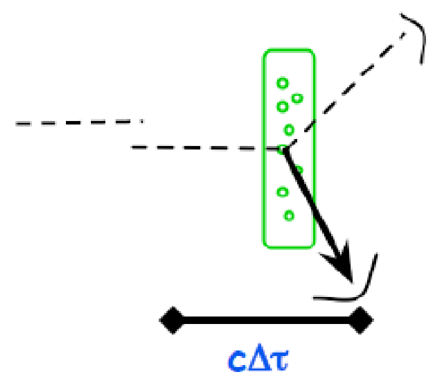
too many electrons in the target over the time interval $\Delta\tau$
lots of random coincidences

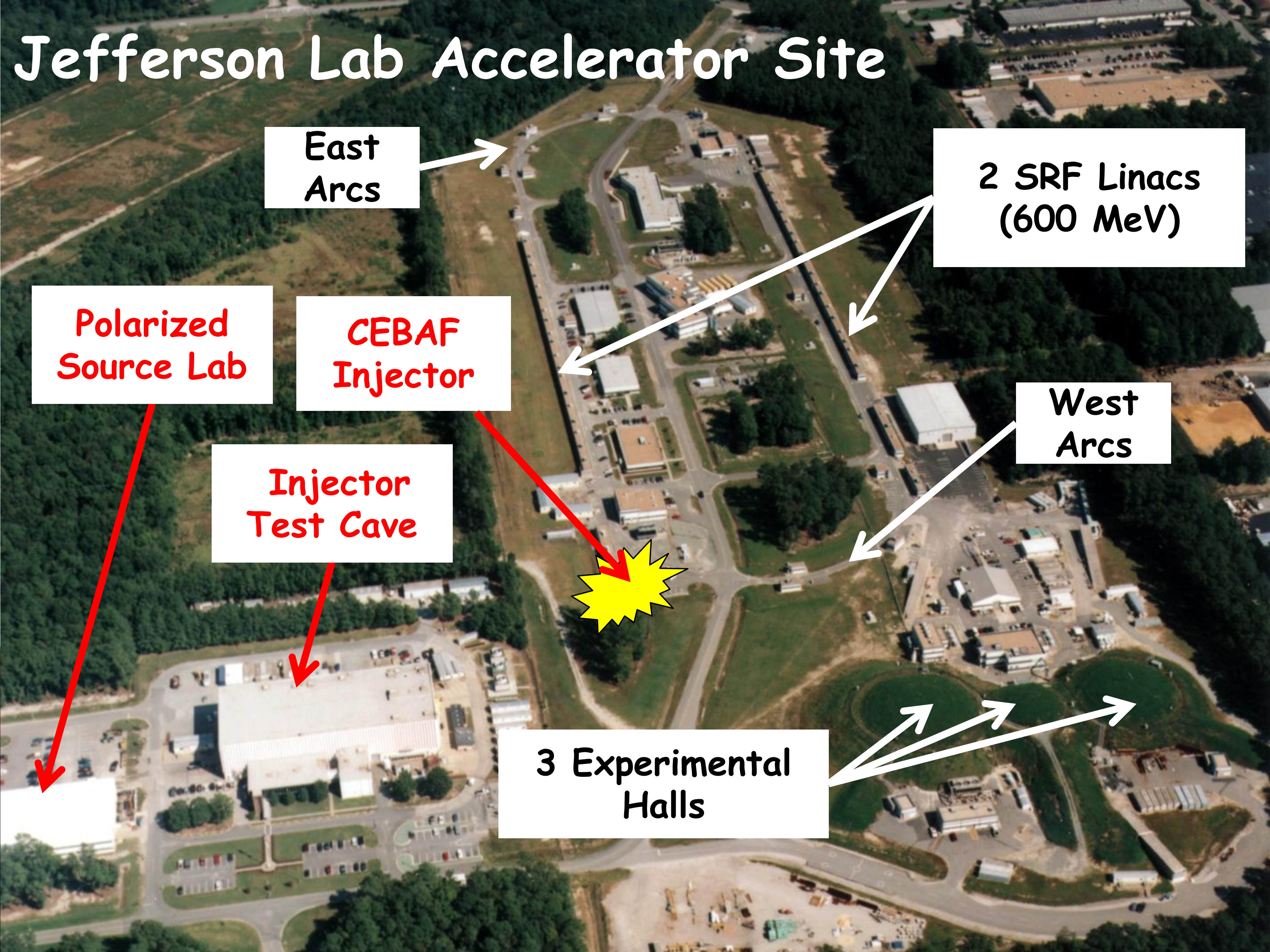


- ★ Advantages of a continuous beam with the same average current



few electrons in the target --
few random coincidences





Jefferson Lab Accelerator Site
East Arcs
2 SRF Linacs (600 MeV)
Polarized Source Lab
CEBAF Injector
West Arcs
Injector Test Cave
3 Experimental Halls

Continuous Electron Beam Accelerator Facility

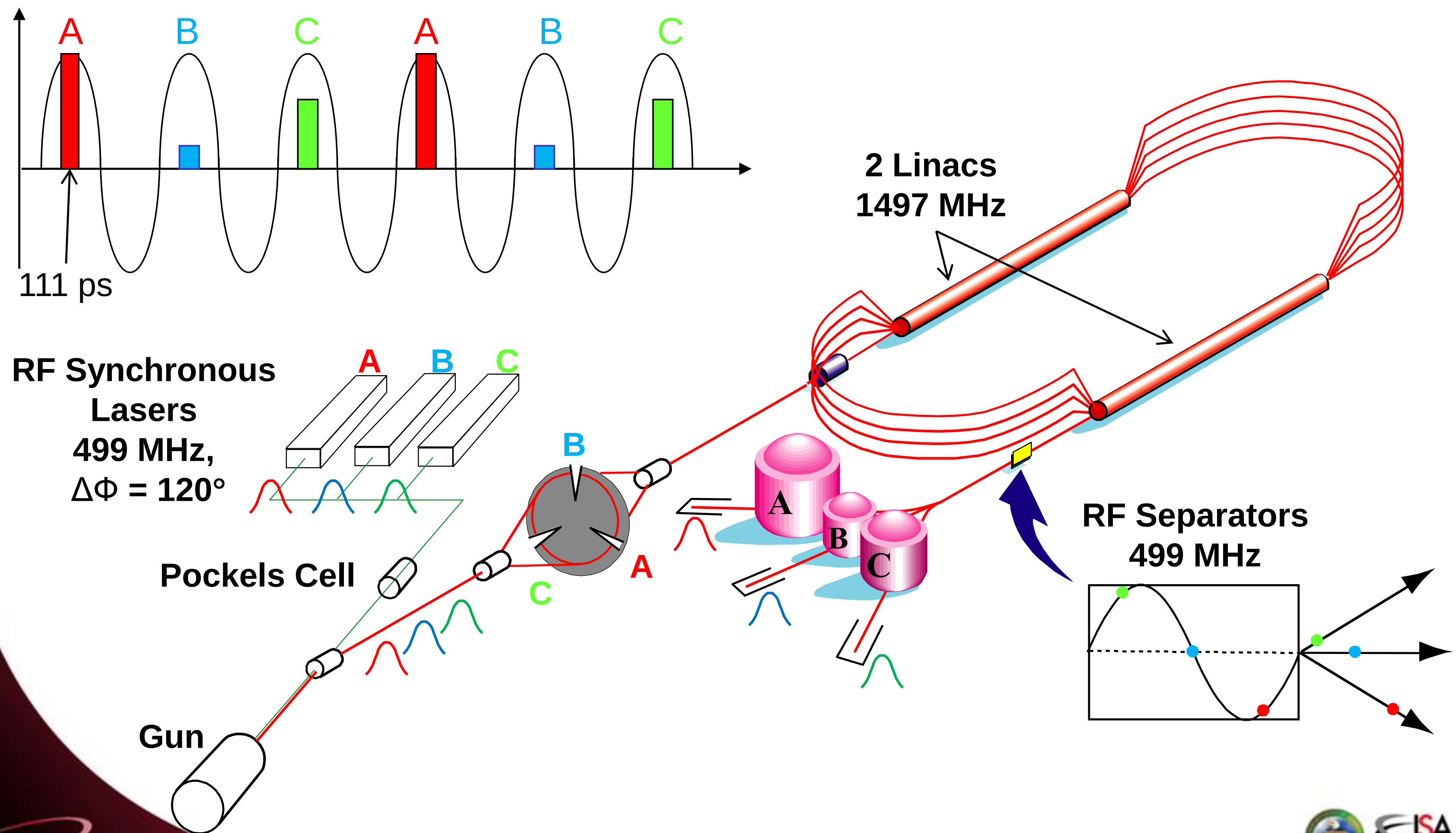
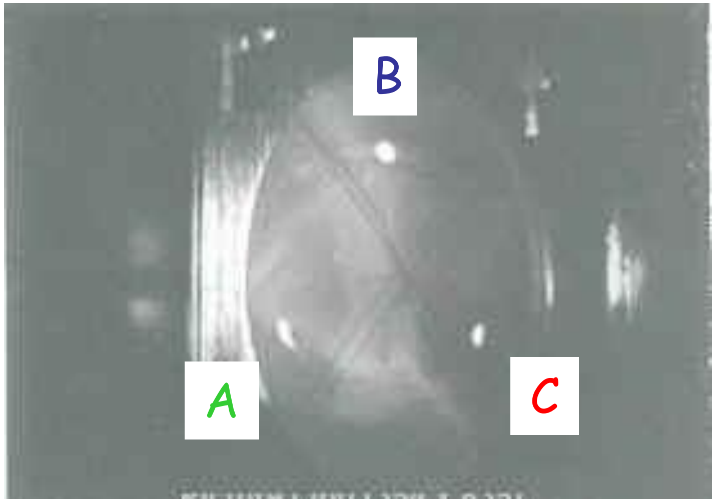
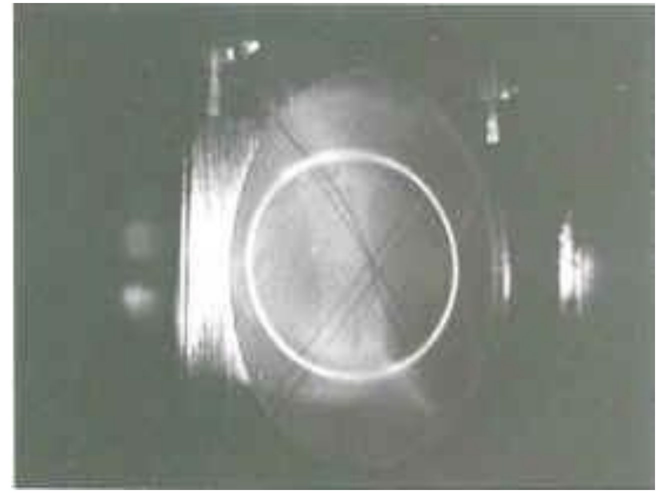


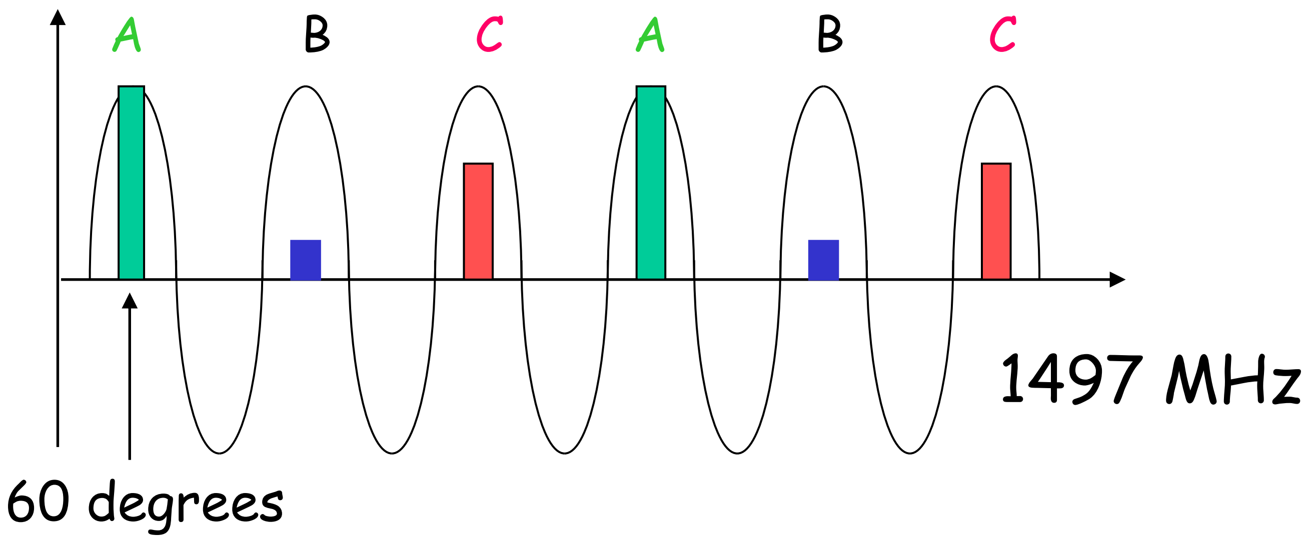
Photo Finish, but at 2 billionths of a second !!!

3 lasers pulsing

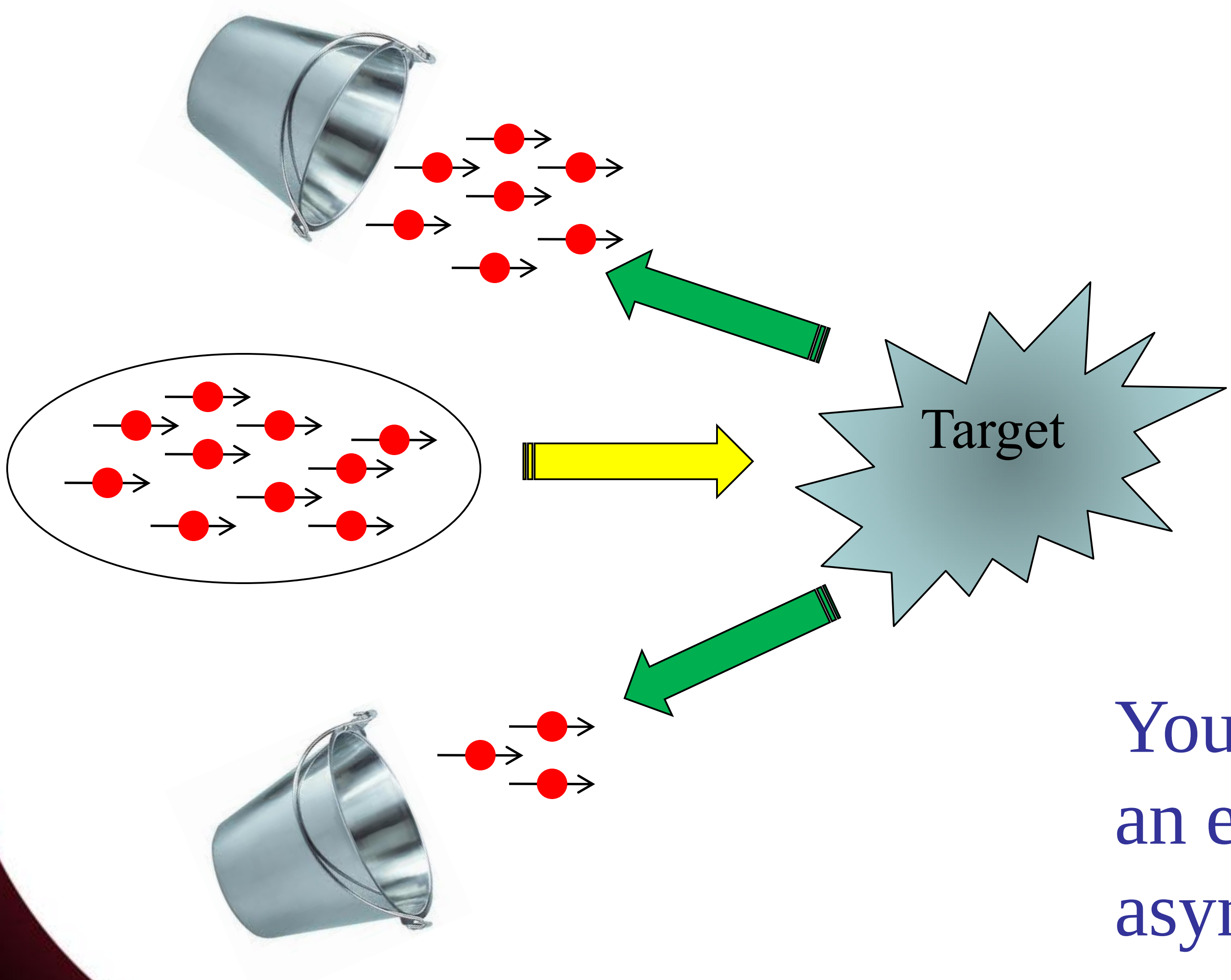


DC beam, not so useful





What about the probing with spin ?

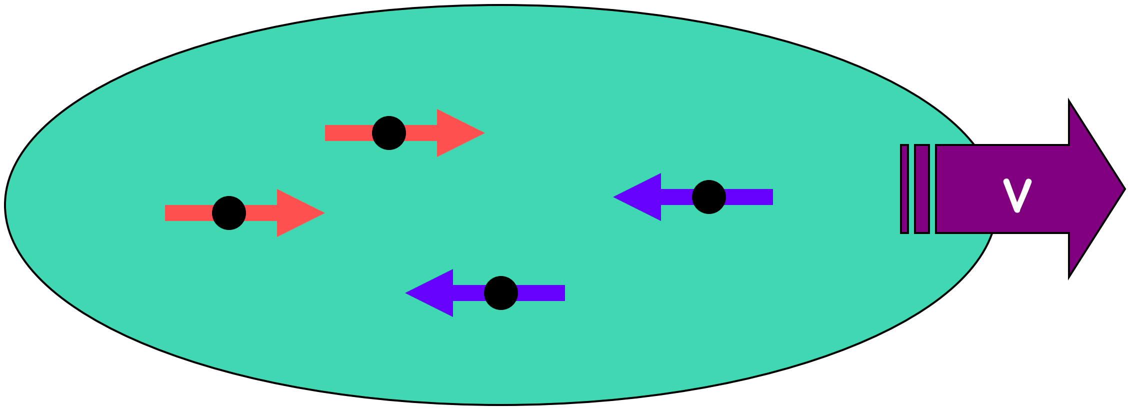


You measure
an experimental
asymmetry

Electron Bunch Spin & Polarization

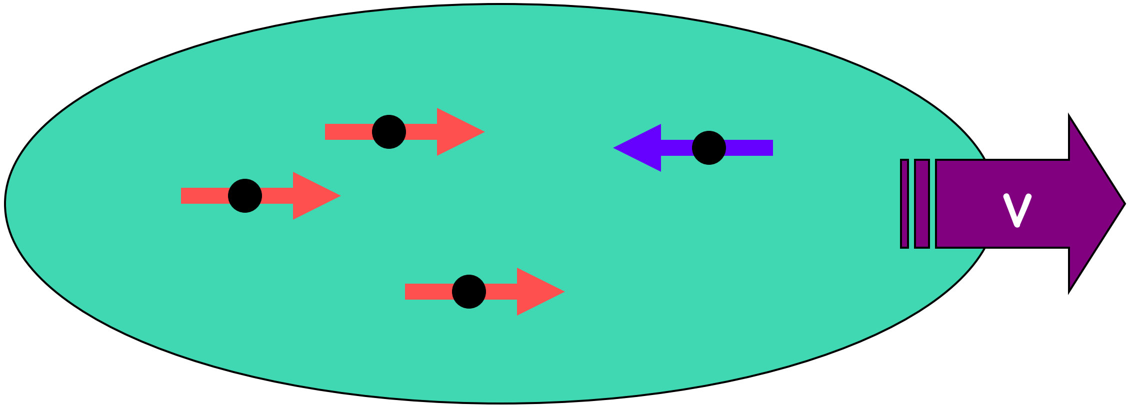
0% Polarization

☹



50% Polarization

☺

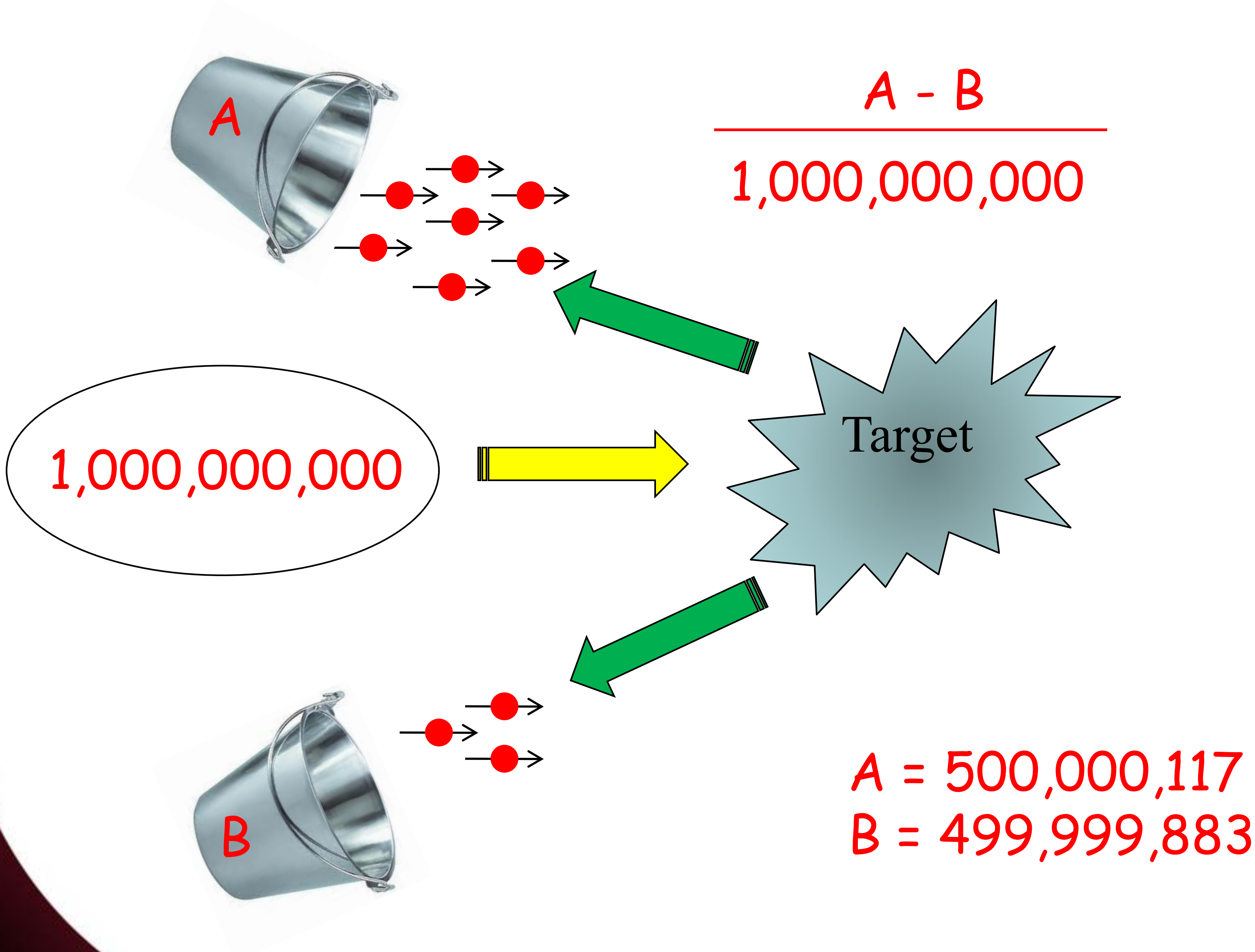


Parity Violation Experiments at CEBAF

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

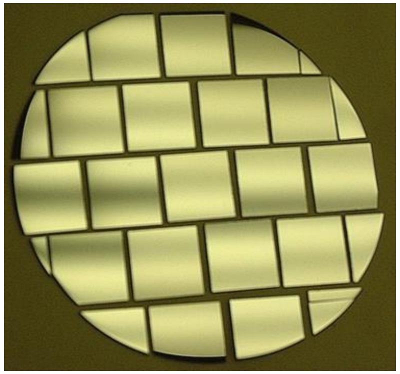
What does “234 ppb” even mean?



Polarized Electron Source "Musts"

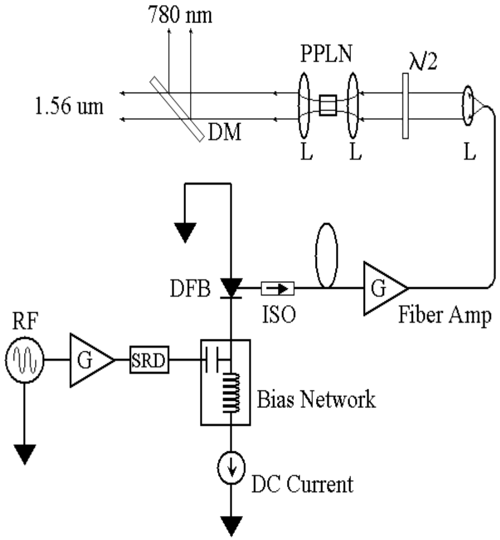
Good Photocathode

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



Good Laser

- Lots of Photons
- CW Pulses
- High Polarization



Good Electron Gun

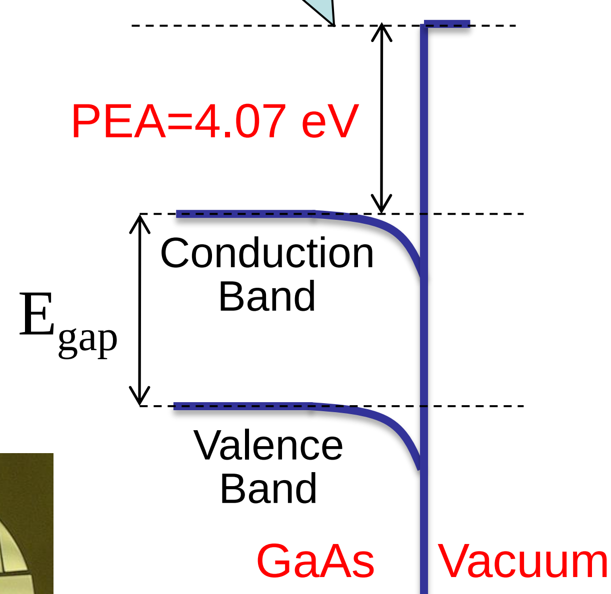
- Accelerate Electrons
- Happy Photocathode
- Integrate Laser

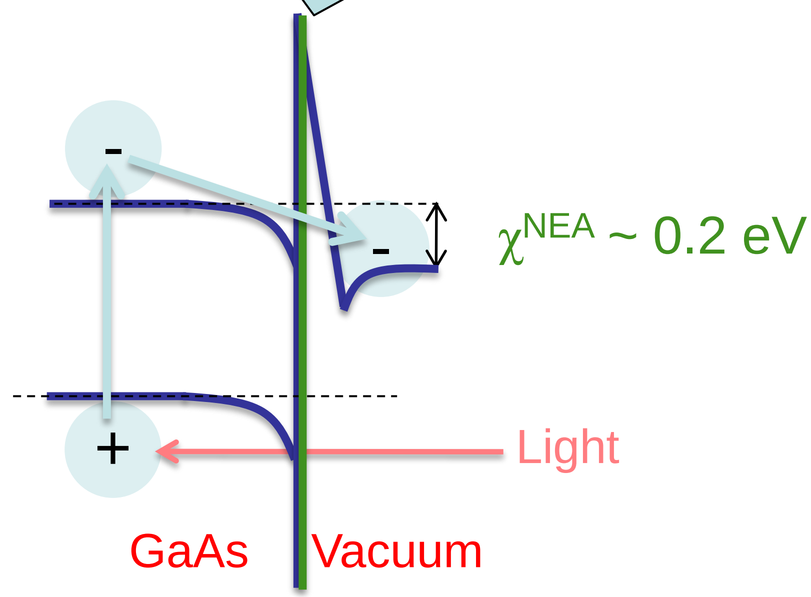
Photoemission from GaAs

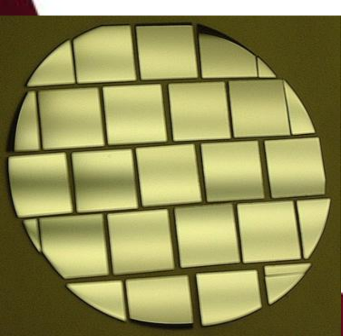
Bare GaAs surface
- Large Work Function
- Positive Electron Affinity (PEA)

NEA Surface Activation

Dipole layers of Cesium + NF_3
- Reduces Work Function
- Negative Electron Affinity (NEA)



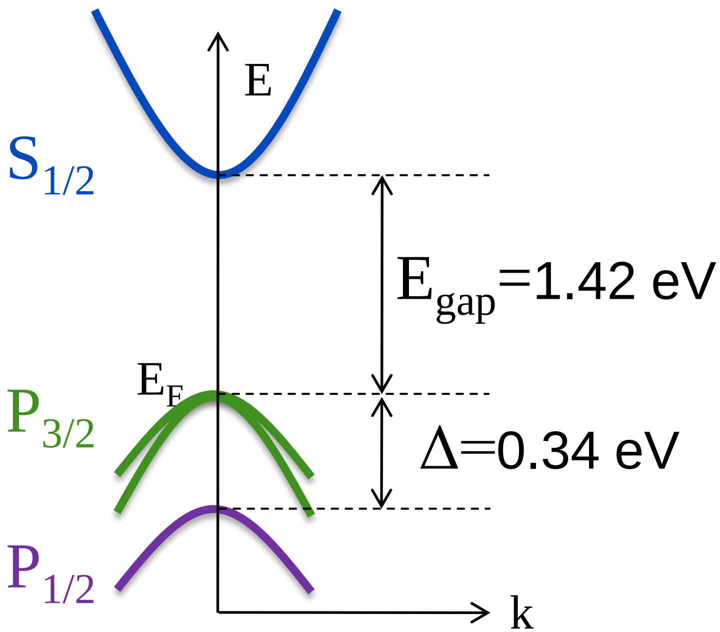


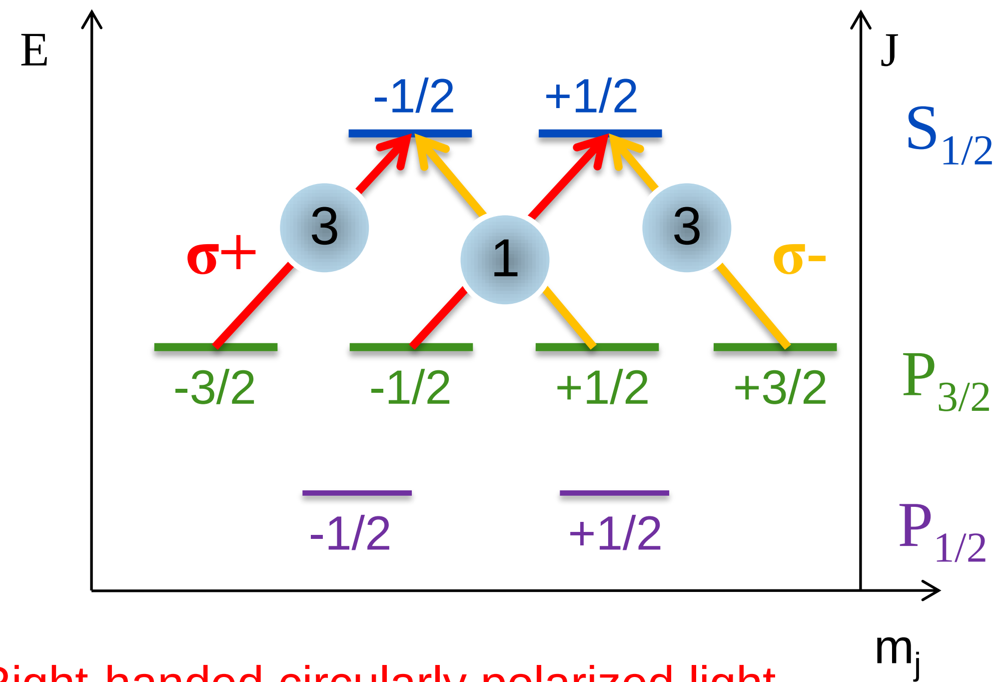


$$\text{Quantum Efficiency} = N_{e-} / N_{\gamma}$$

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

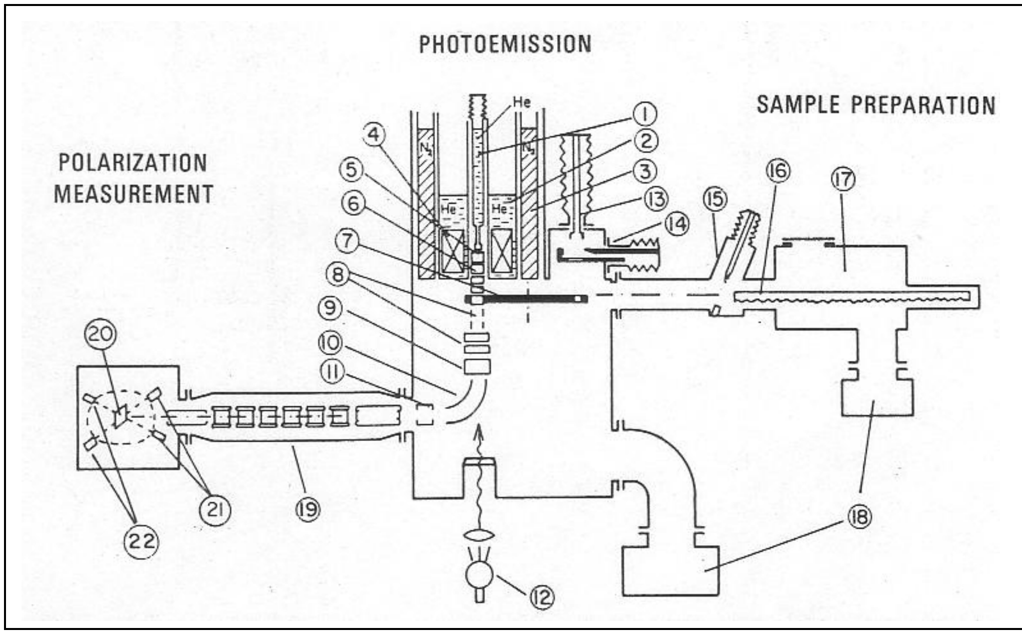
The First GaAs Photoemission Source

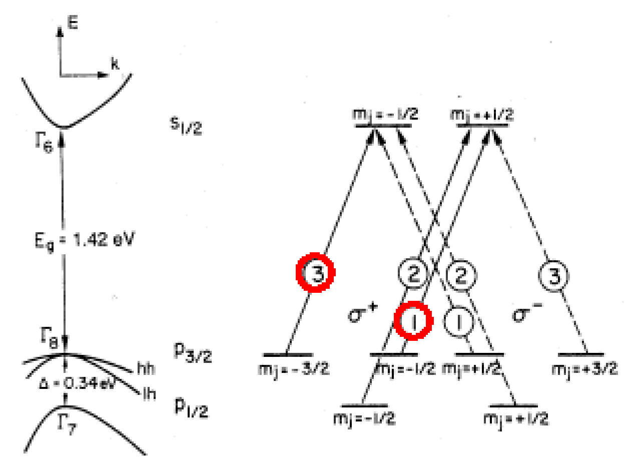
PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

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)





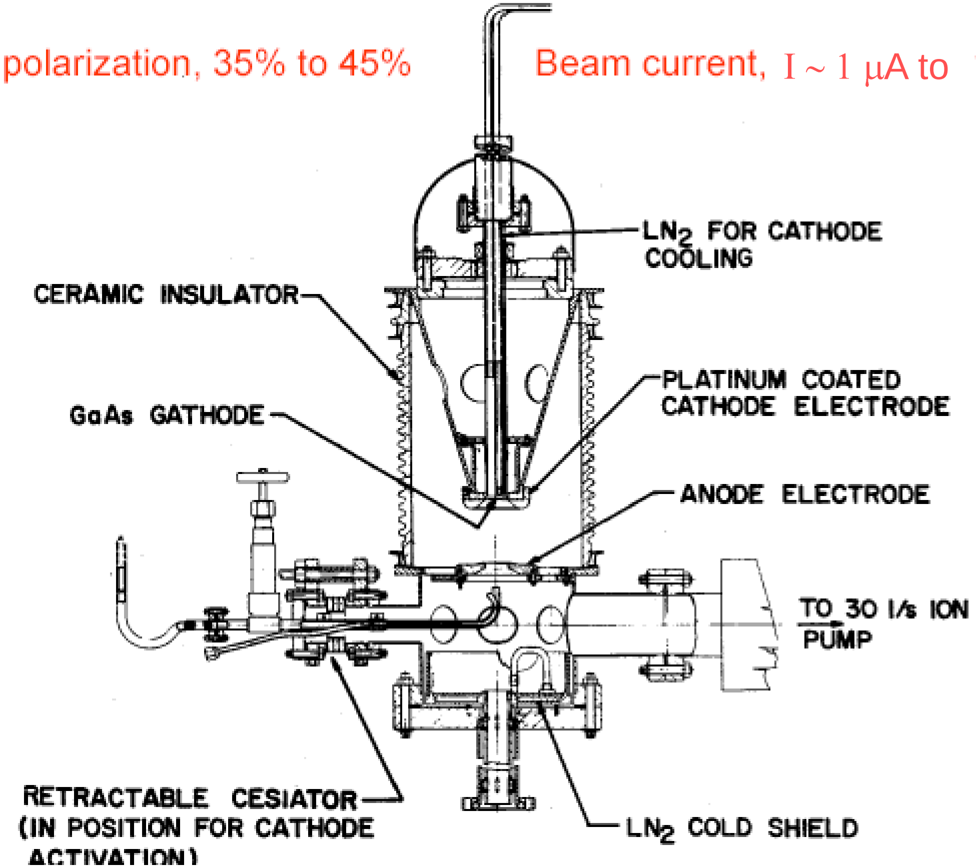
$$P = \frac{3-1}{3+1} = 50\%$$

First High Voltage GaAs Photogun

Polarized e⁻ Gun for SLAC Parity Violation Experiment

Beam polarization, 35% to 45%

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



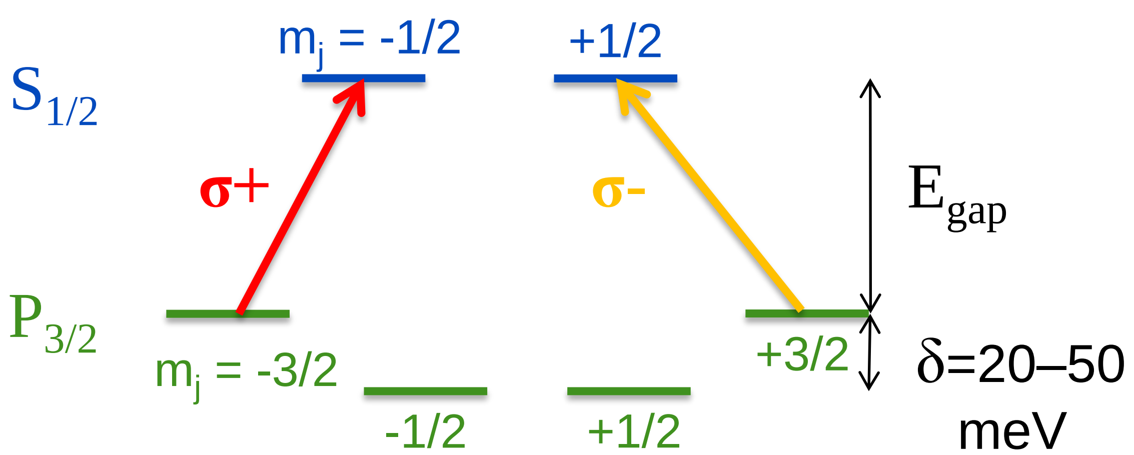
Electrons into the accelerator Dec., 1977

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 $S_{1/2}$:
  $E_{gap} < E_{\gamma} < E_{gap} + \delta$



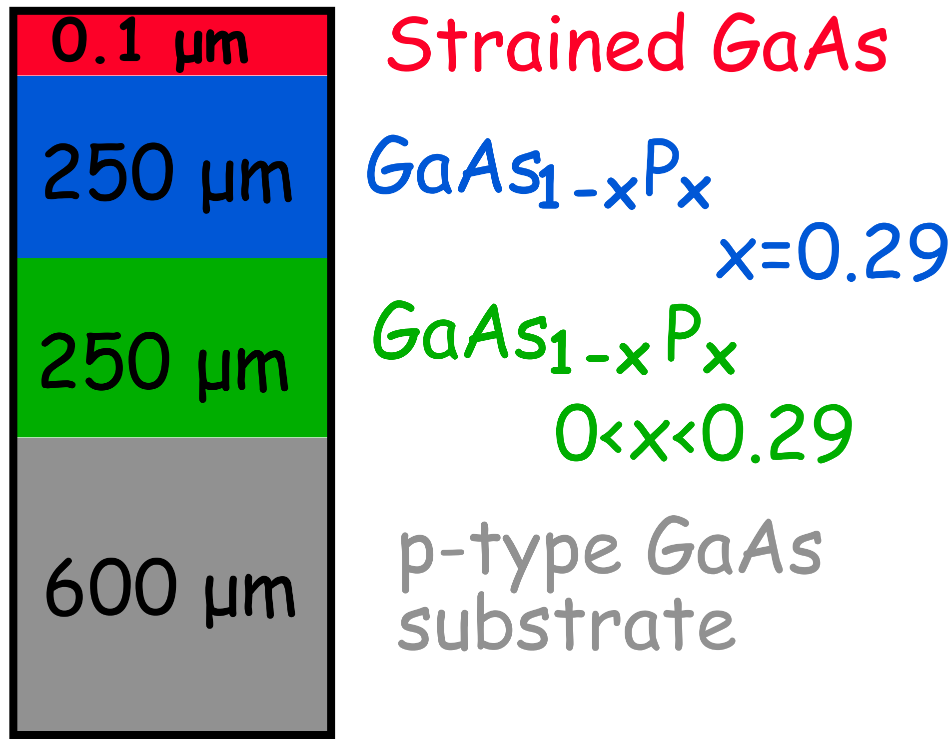
- Higher QE: Alternating layers of GaAs and GaAsP – **Superlattice GaAs**

Strained layer GaAs

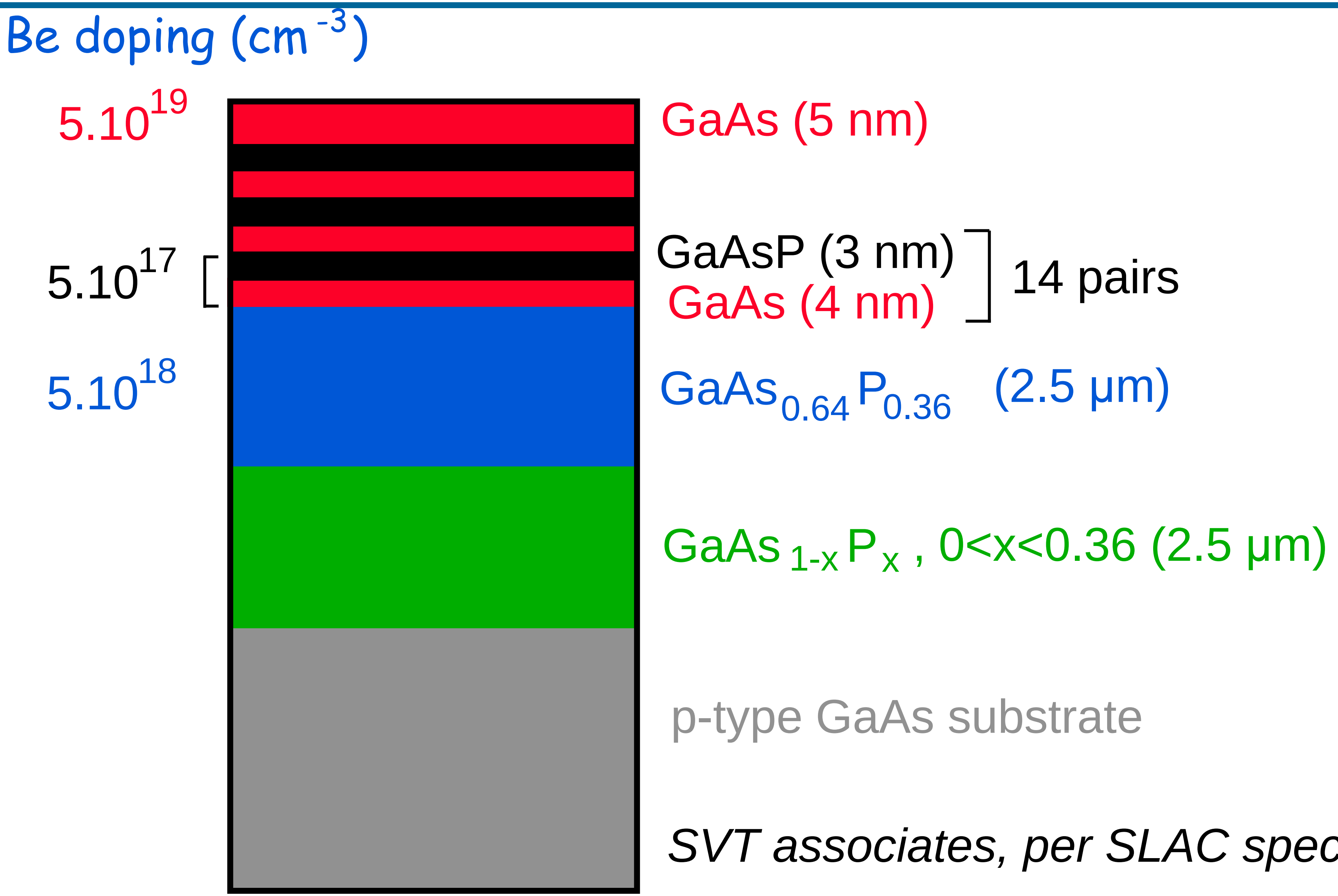
Bandwidth Semiconductor (formerly *SPIRE*)

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

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

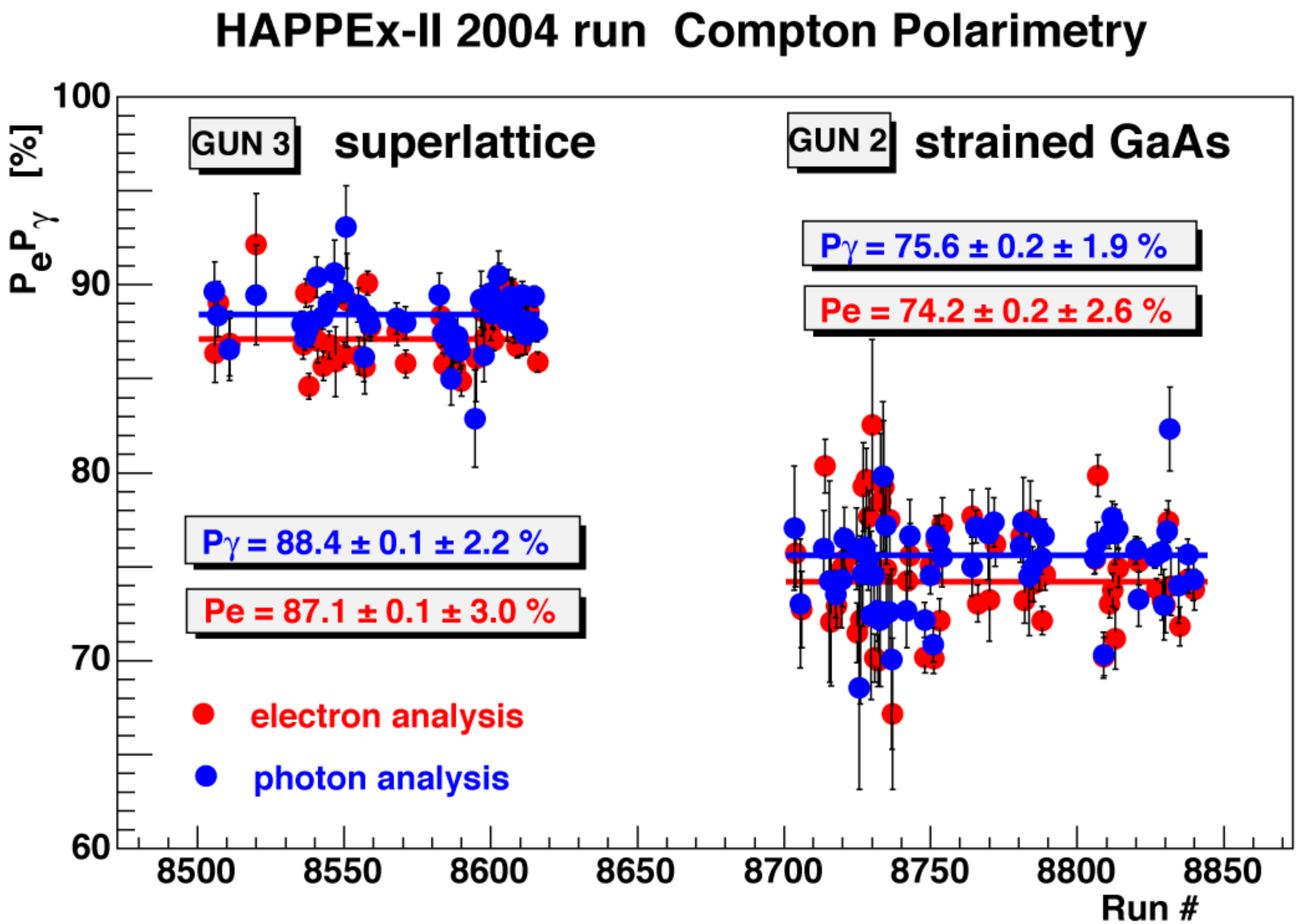


Strained Layer - Superlattice GaAs



SVT associates, per SLAC specs.

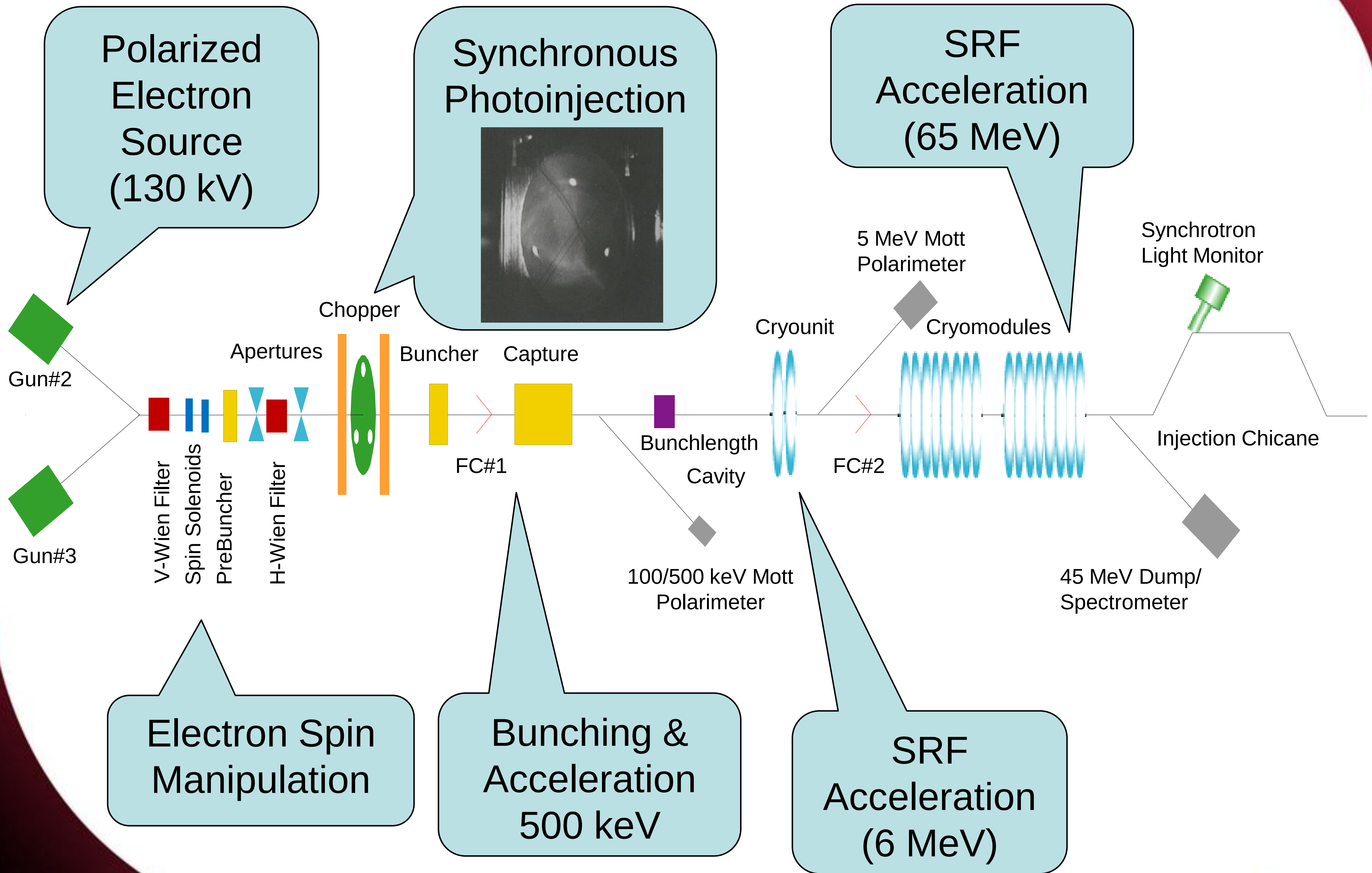
And, it really works!



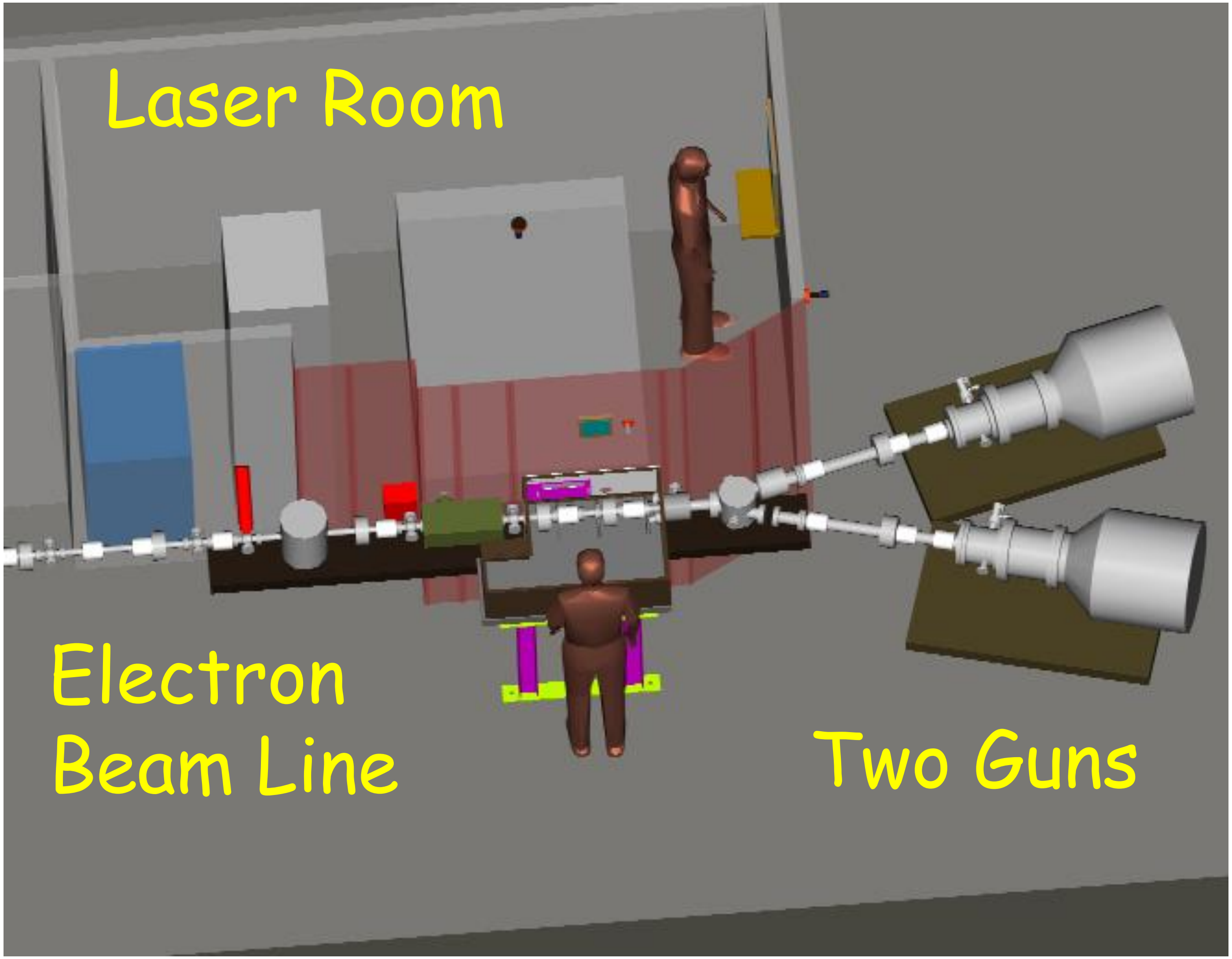
Experiment Figure of Merit

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

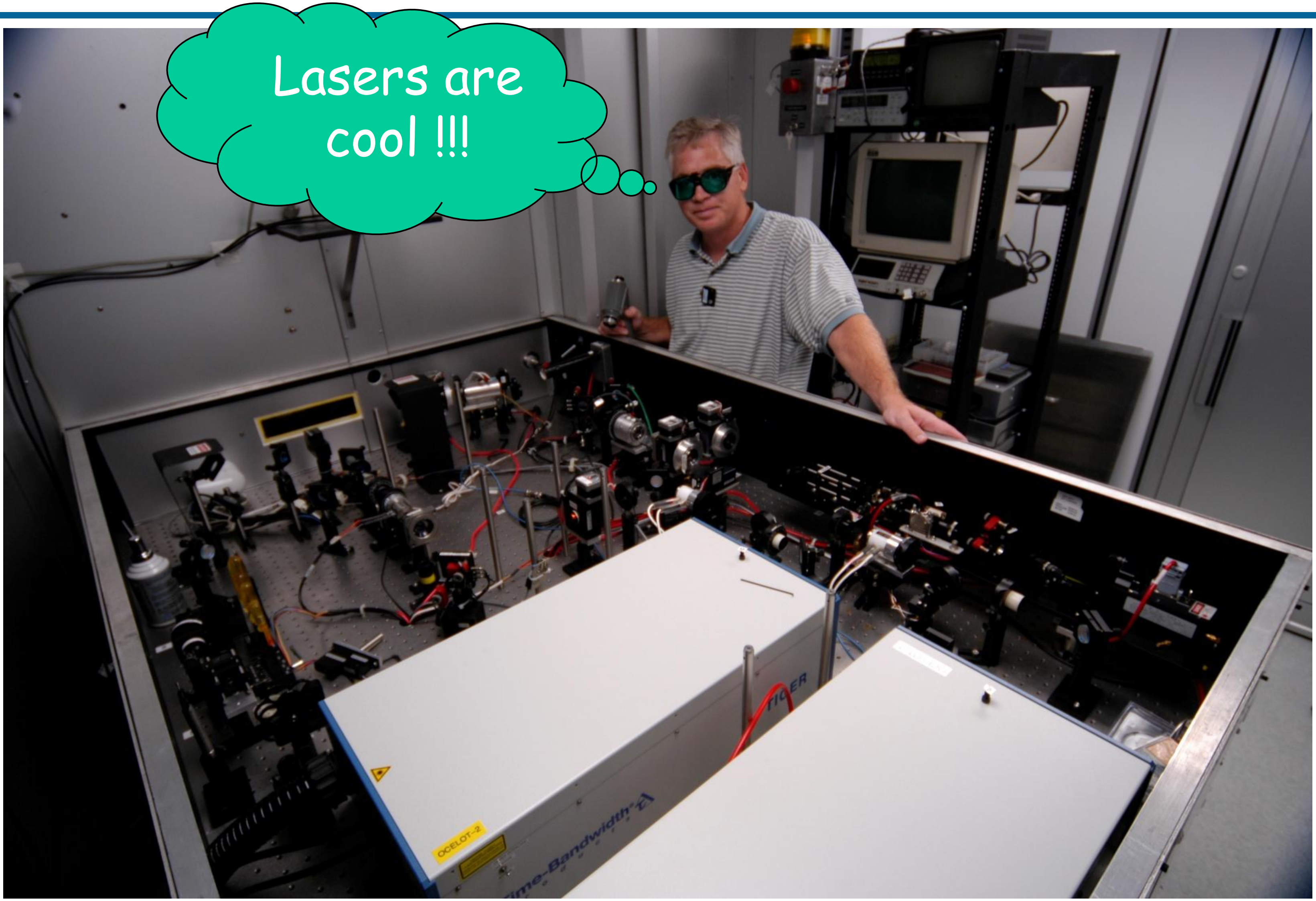
Polarized Electron Injector

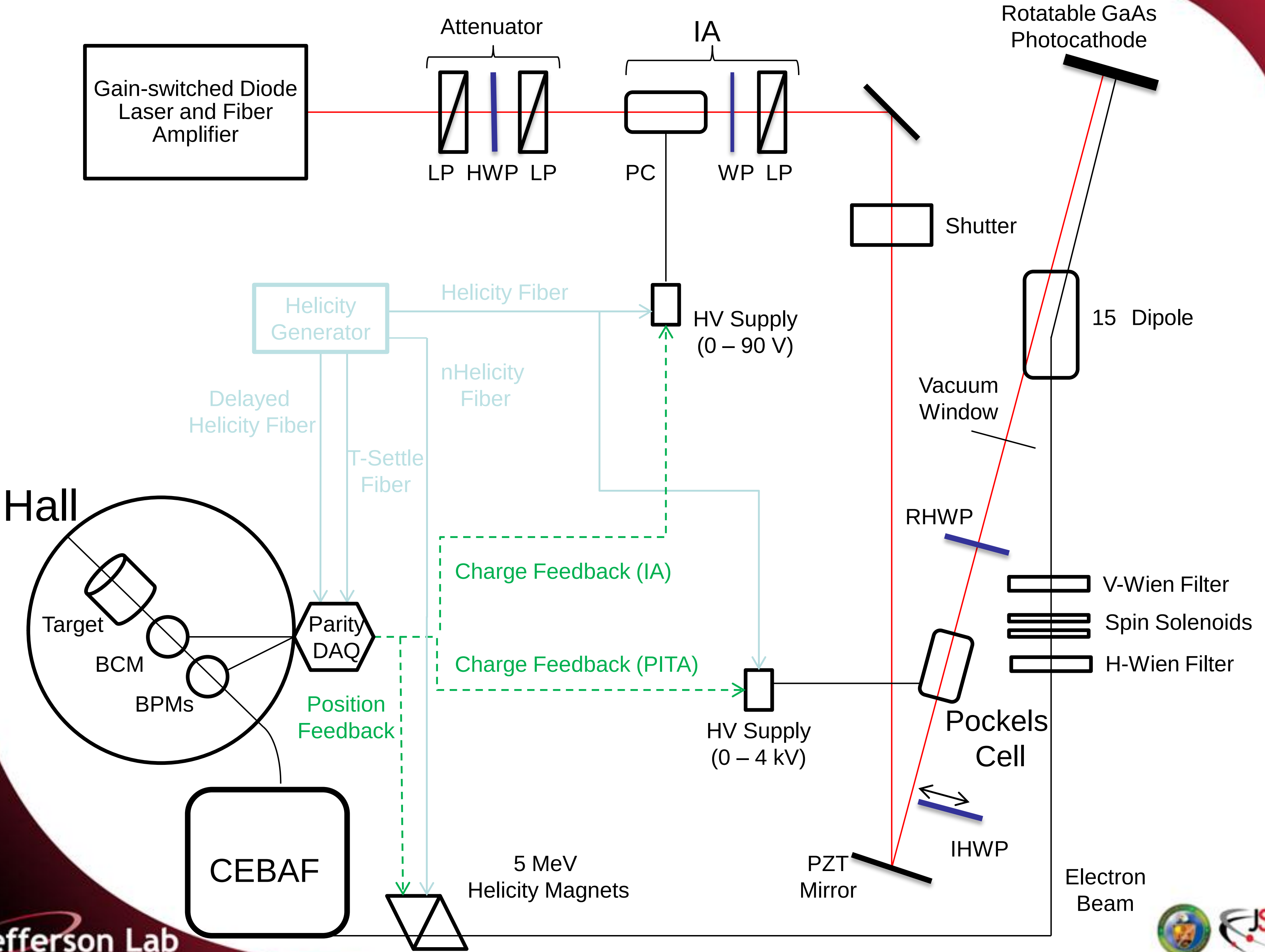


Bird's Eye View



Laser Room for Dust & Climate Control

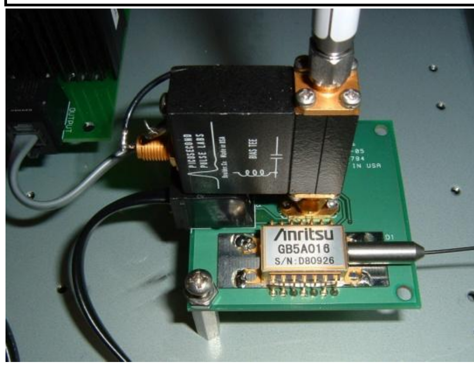


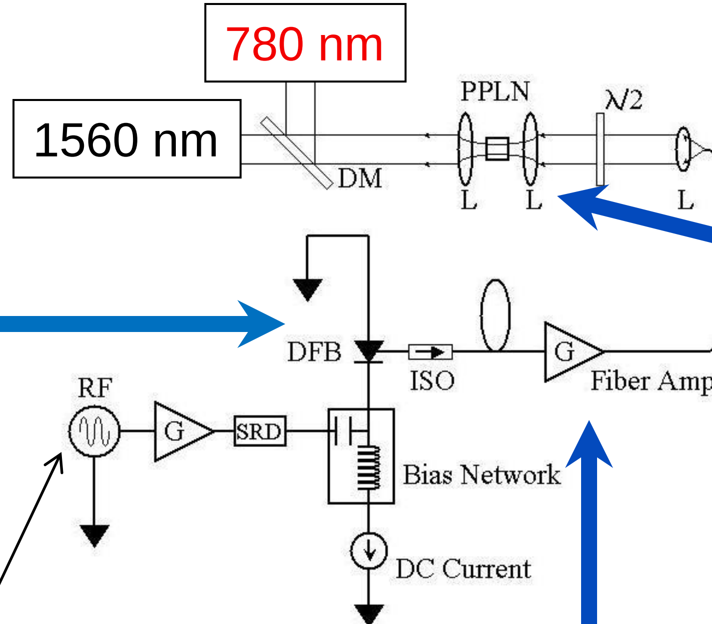


Gain-switched Diode Laser and Fiber Amplifier
Attenuator
LP HWP LP
IA
PC
WP LP
Rotatable GaAs Photocathode
Shutter
Helicity Generator
Helicity Fiber
HV Supply (0 – 90 V)
15 Dipole
nHelicity Fiber
Delayed Helicity Fiber
T-Settle Fiber
Vacuum Window
Hall
RHWP
Charge Feedback (IA)
V-Wien Filter
Spin Solenoids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

Fiber-based Drive Laser

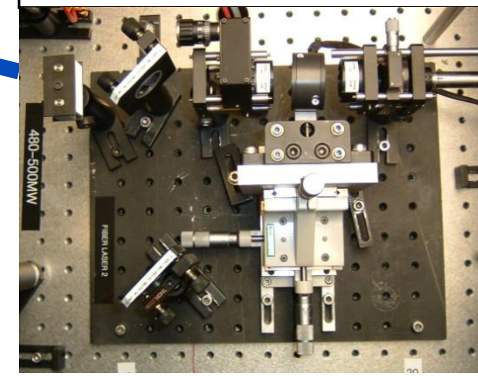
RF Locked Low-Power
(1 mW)
1560 nm Fiber Diode

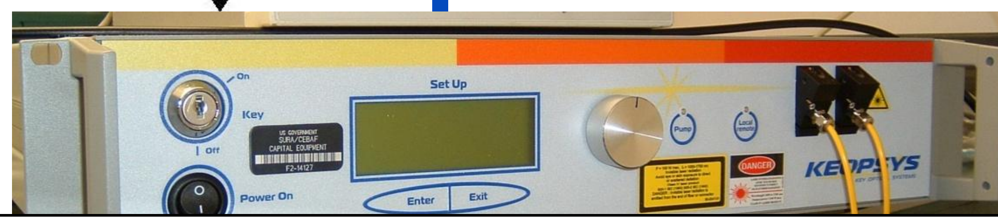




499 MHz

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





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

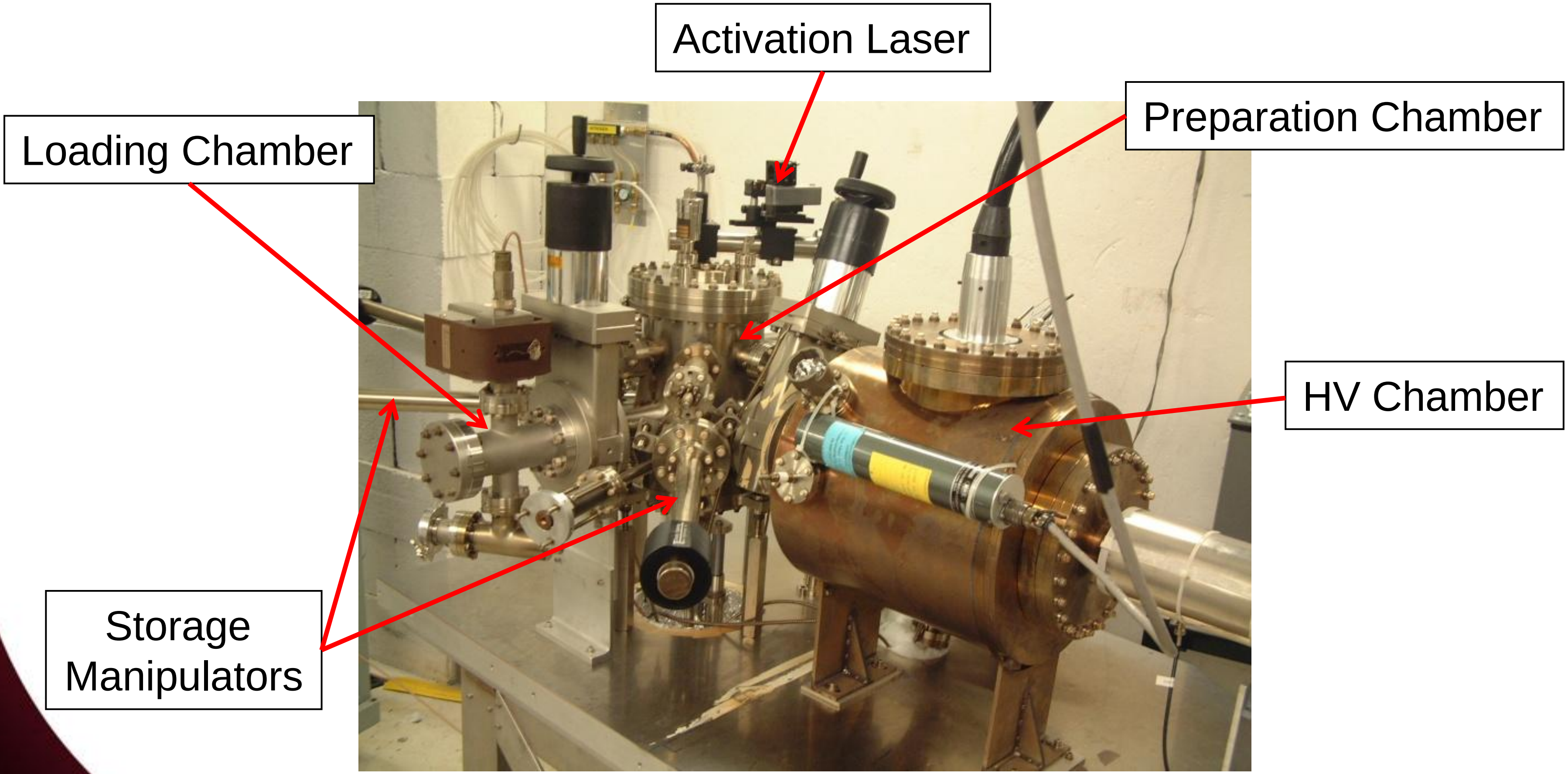
J. Hansknecht* and M. Poelker

Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, Virginia 23606, USA
(Received 12 April 2006; published 21 June 2006)

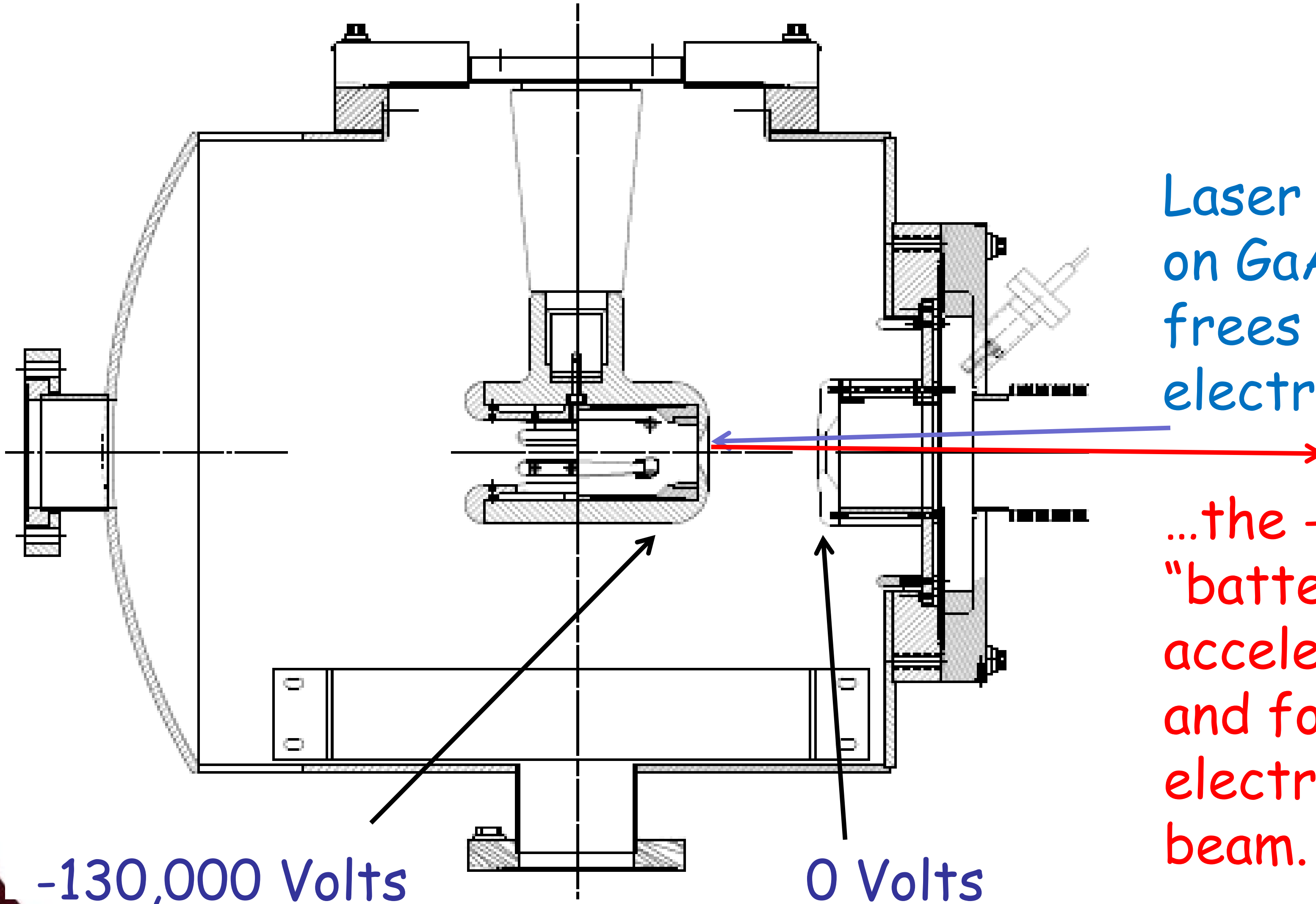
Light at 1560 nm from a gain-switched fiber-coupled diode laser and ErYb-doped fiber amplifier was frequency doubled to obtain over 2 W average power at 780 nm with ~40 ps pulses and pulse repetition rate of 499 MHz. This light was used to drive the 100 kV DC high voltage GaAs photoemission gun at the

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



Electron Gun Cut-Away



Laser shines on GaAs & frees the electrons…

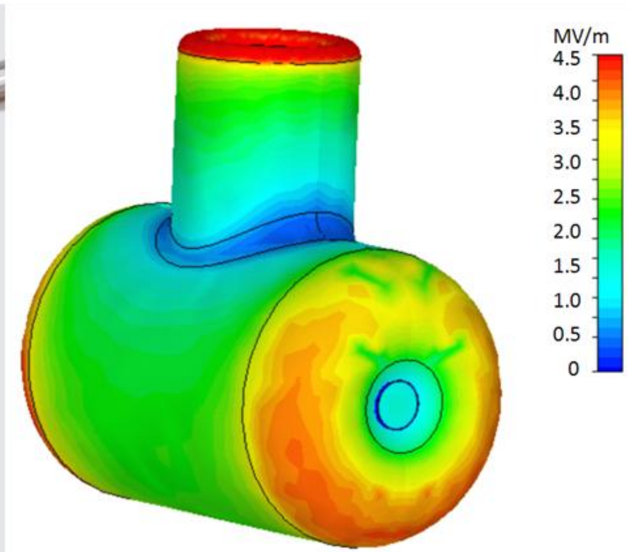
…the -130kV "battery" accelerates and forms the electron beam.

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

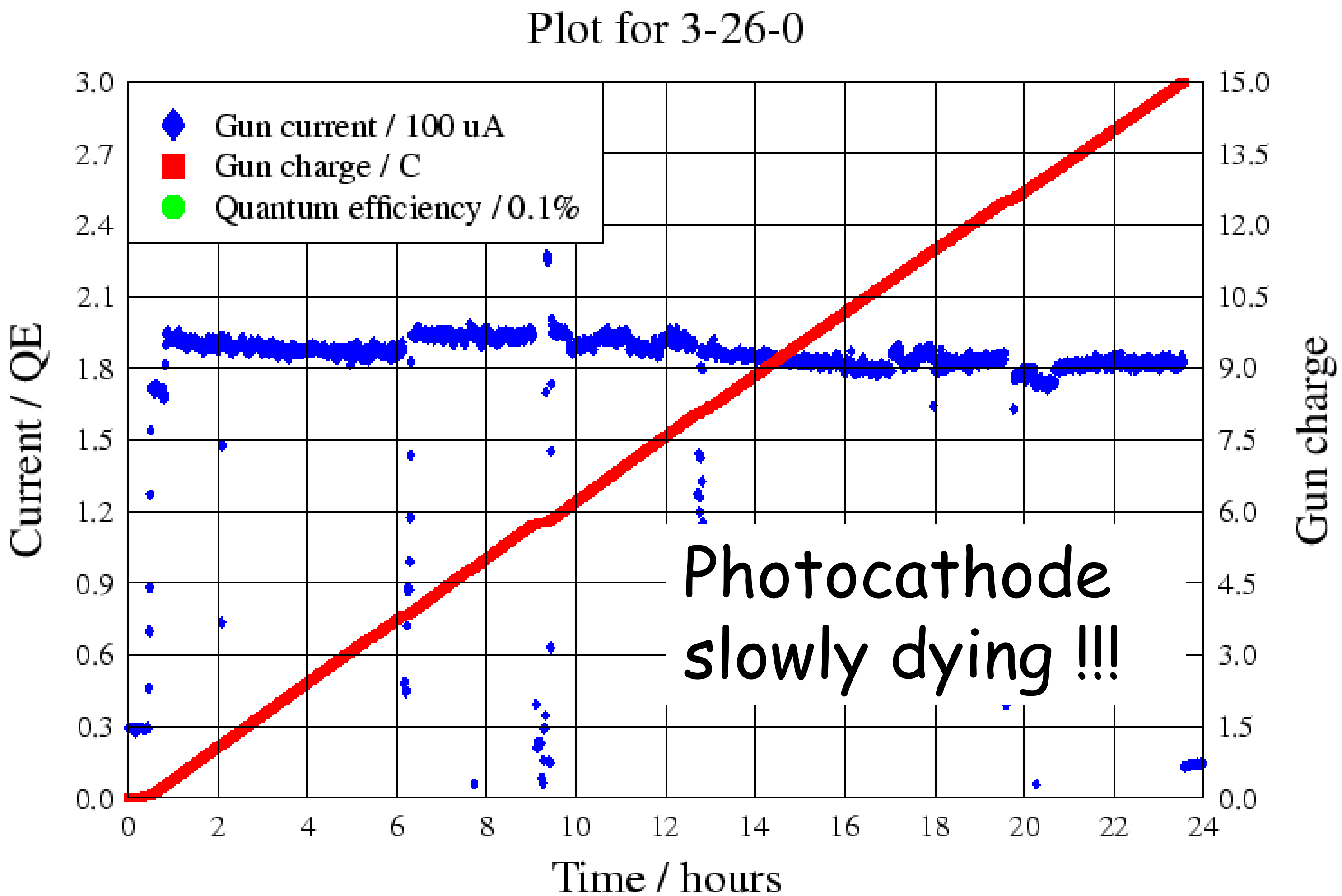
Load-locked dc high voltage GaAs photogun with an inverted-geometry ceramic insulator

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)

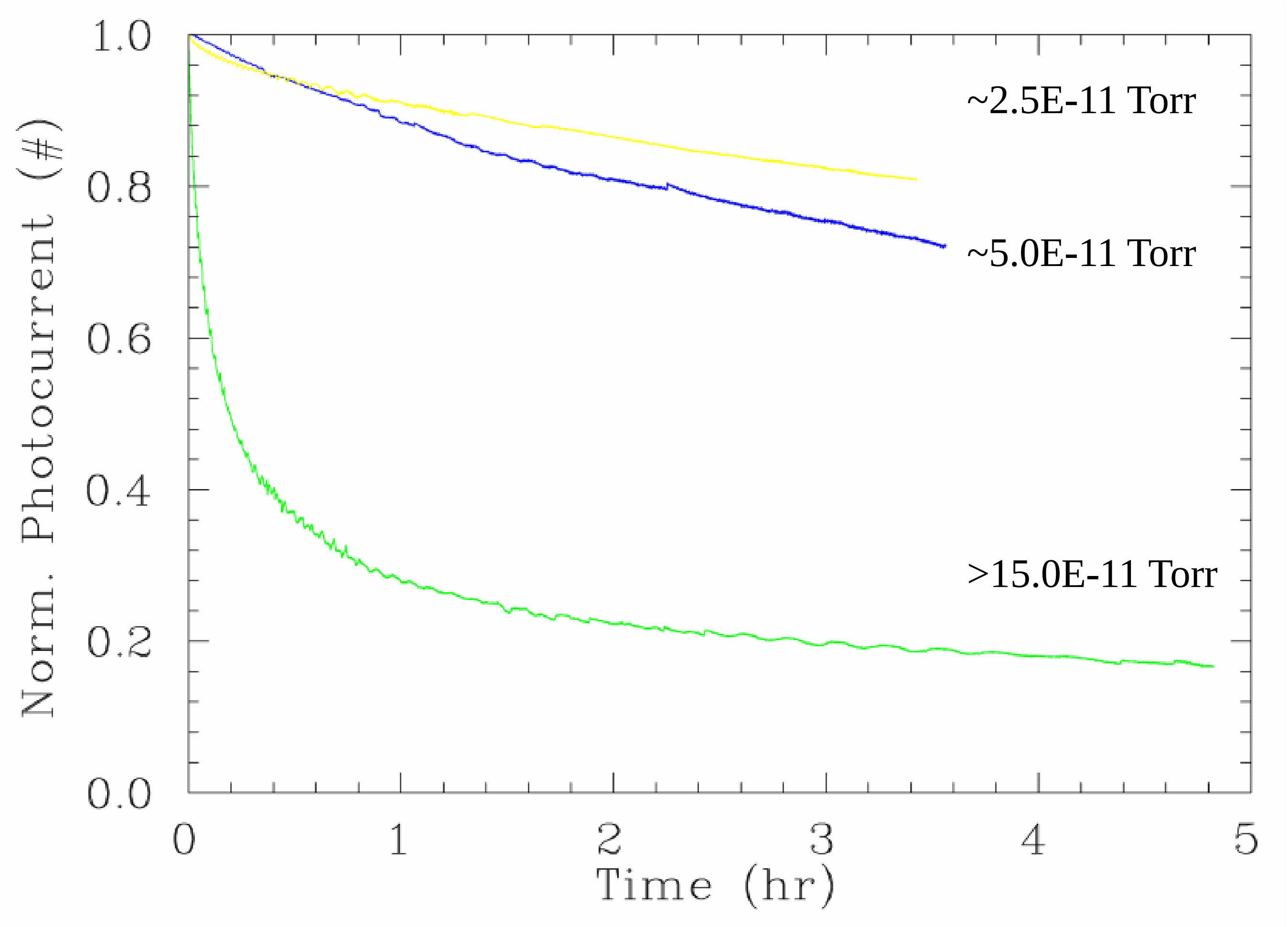
A new dc high voltage spin-polarized photoelectron gun has been constructed that employs a compact inverted-geometry ceramic insulator. Photogun performance at 100 kV bias voltage is summarized.



Who wants polarized electrons?



Better Vacuum = Longer Lifetime

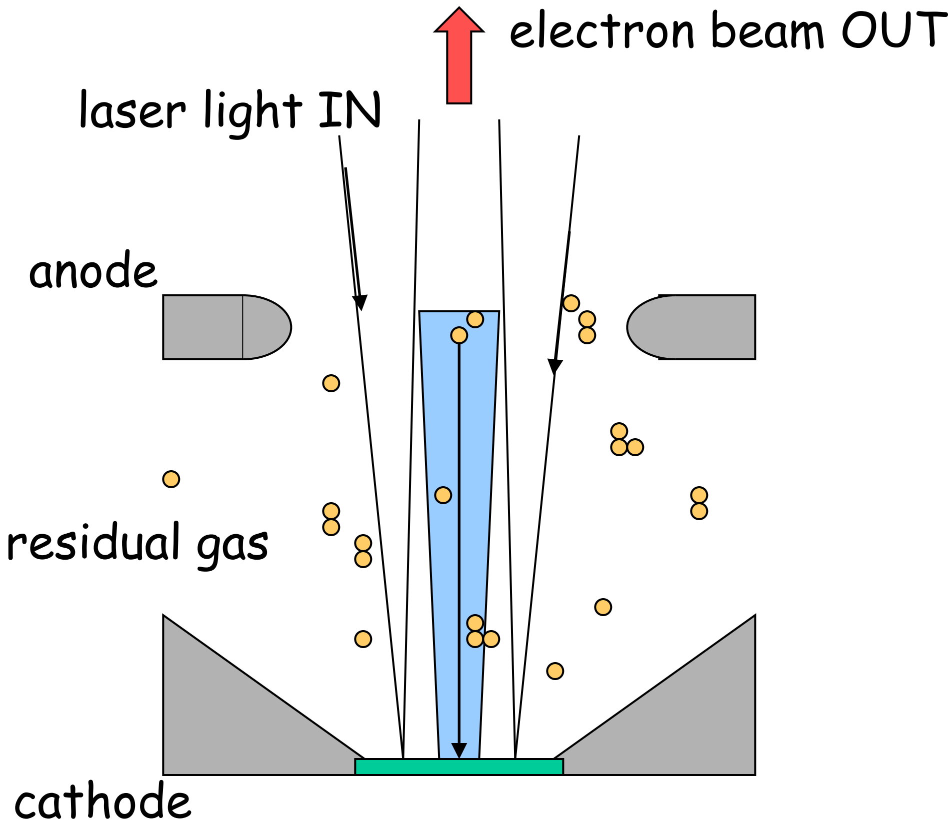


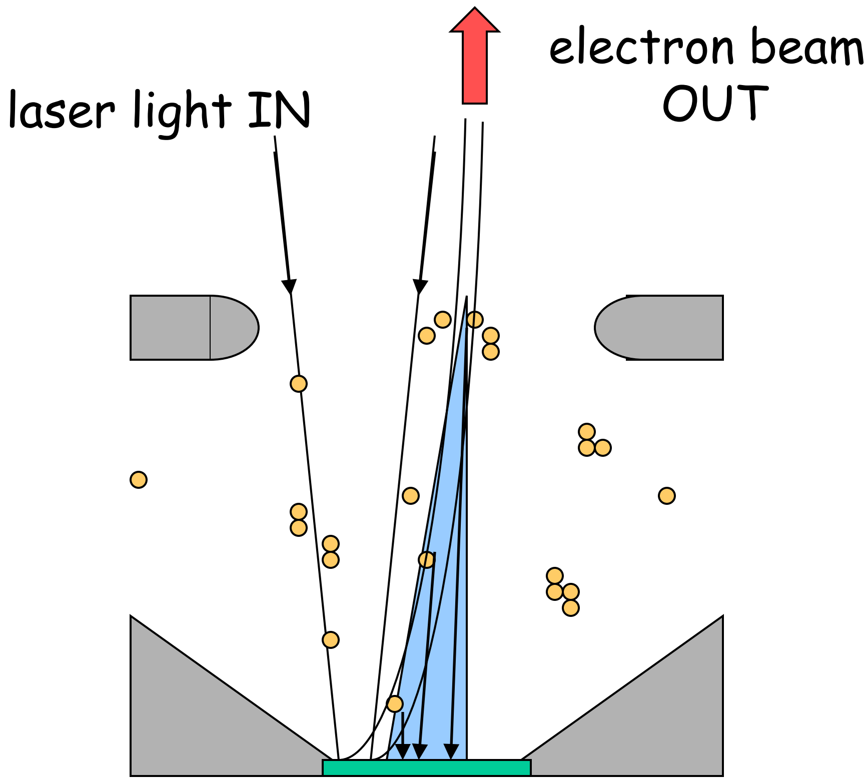
Better Vacuum

Ion Back-Bombardment

High energy ions focused to electrostatic center

We don't run beam from electrostatic center

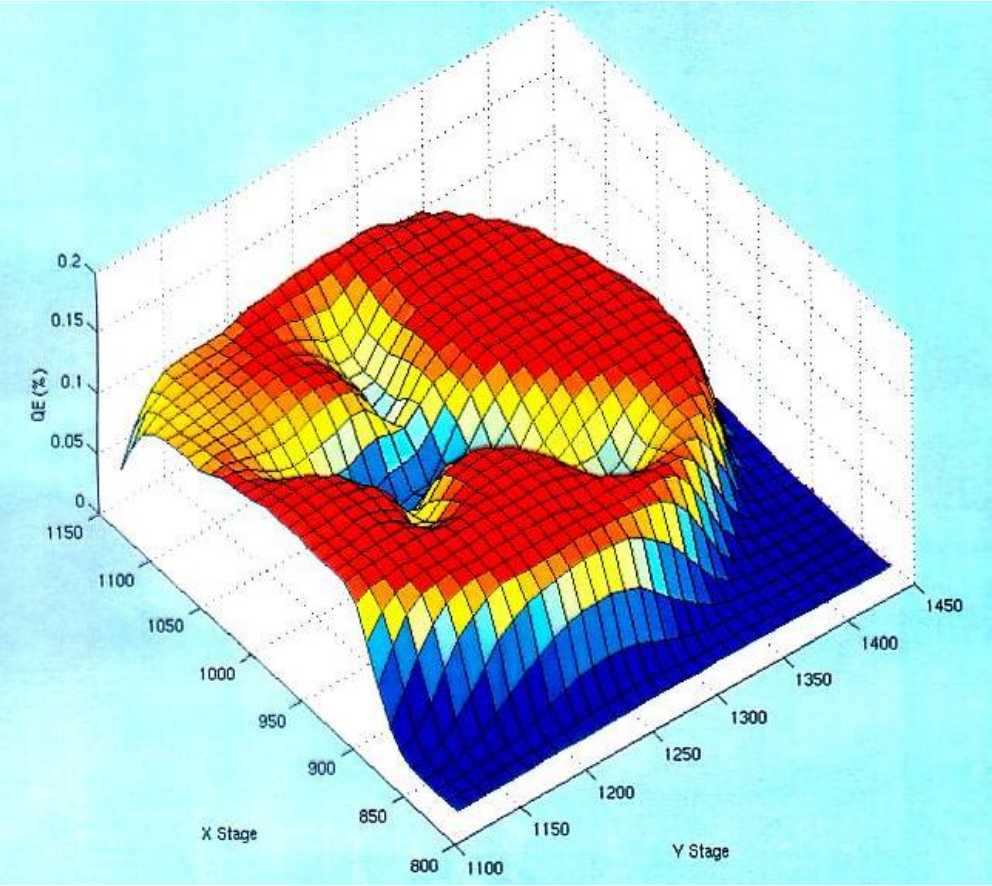


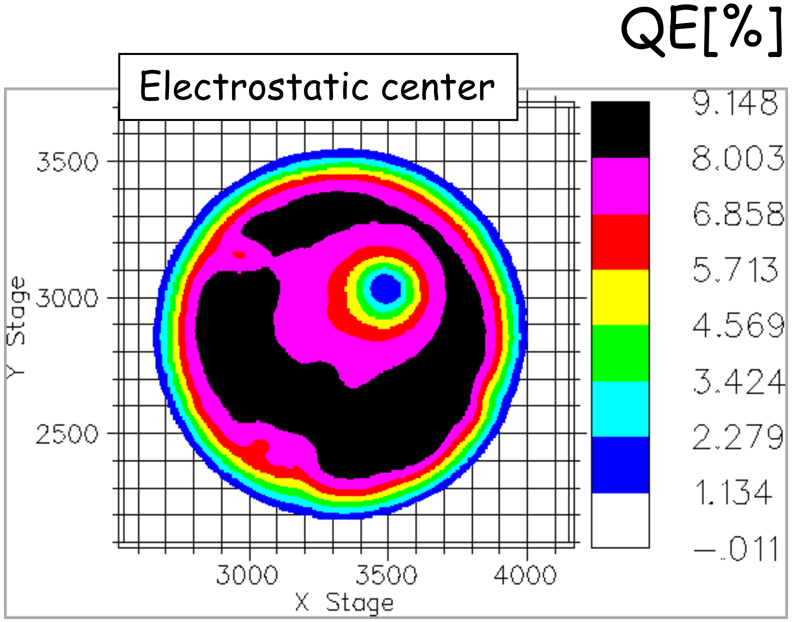


Ions create QE trough to electrostatic center

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.

"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

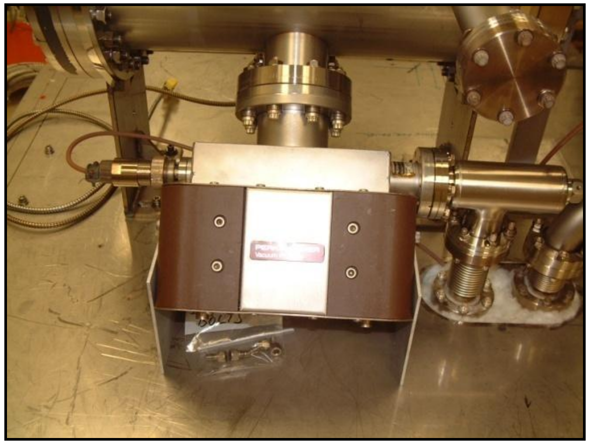
- **Getter Pumps**
  - Chemically active surface
    - Titanium sublimed from hot filament
    - Non-Evaporative Getters
  - Molecules stick when they hit
    - Does not work well for inert gasses such as Argon, Helium or for methane

- **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.

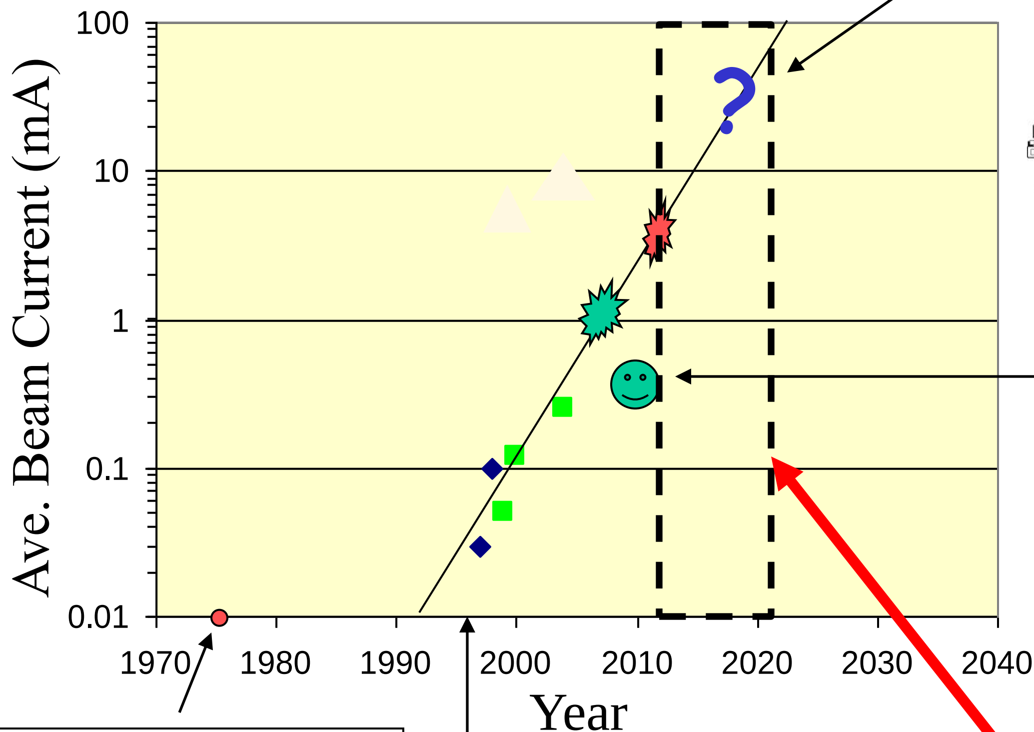
NEG pump array

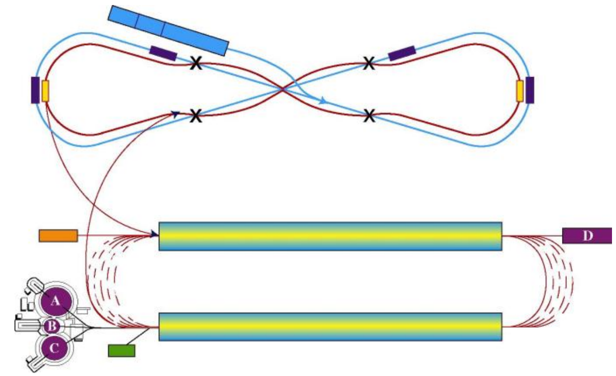


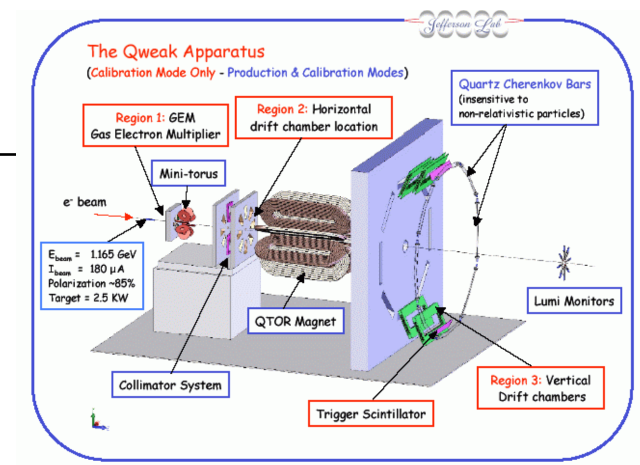
Ion Pump

High Polarization from GaAs: Trending toward higher current…

E(L)IC







First polarized beam from GaAs photogun

First low polarization, then high polarization at CEBAF

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