Highlights of the Polarized Electron/Positron Source Meeting at the 17th International Spin Symposium, Kyoto, Japan
&
Photocathode Lifetime Measurements to 10 mA using the New CEBAF 100 kV GaAs DC Photogun

Joe Grames

CASA Seminar
December 7, 2006

SPIN 2006

The 17th International Spin Physics Symposium

Kyoto Japan Oct. 2-7 '06

Symposium Topics

- Fundamental Symmetries and Spin
- Spin Structure of Nucleons
- Spin Beyond the Standard Model
- Spin in Hadronic Reactions
- Spin Physics with Photons and Leptons
- Spin Physics in Nuclei
- Spin Physics with RI Beams
- Acceleration, Storage, and Polarimetry of Polarized Beams
- **Polarized Ion and Electron Sources and Targets**
- Future Facilities and Experiments

Session 9B : Polarized electron (positron) sources

- Presentations
  - **oral** : 15
  - **poster** : 6

- JLAB
- SLAC
- University of Mainz
- University of Bonn
- CERN
- DESY
- St. Petersburg
- KEK
- Osaka Electro-Communication University
- Rikkyo University
- Nagoya University

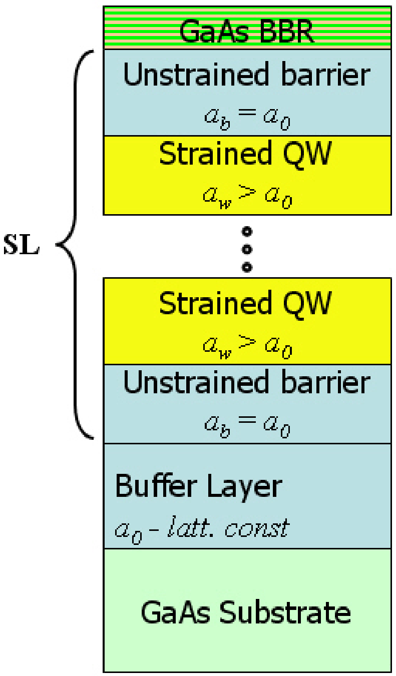
http://spin.phys.nagoya-u.ac.jp/~spweb/spin2006.html

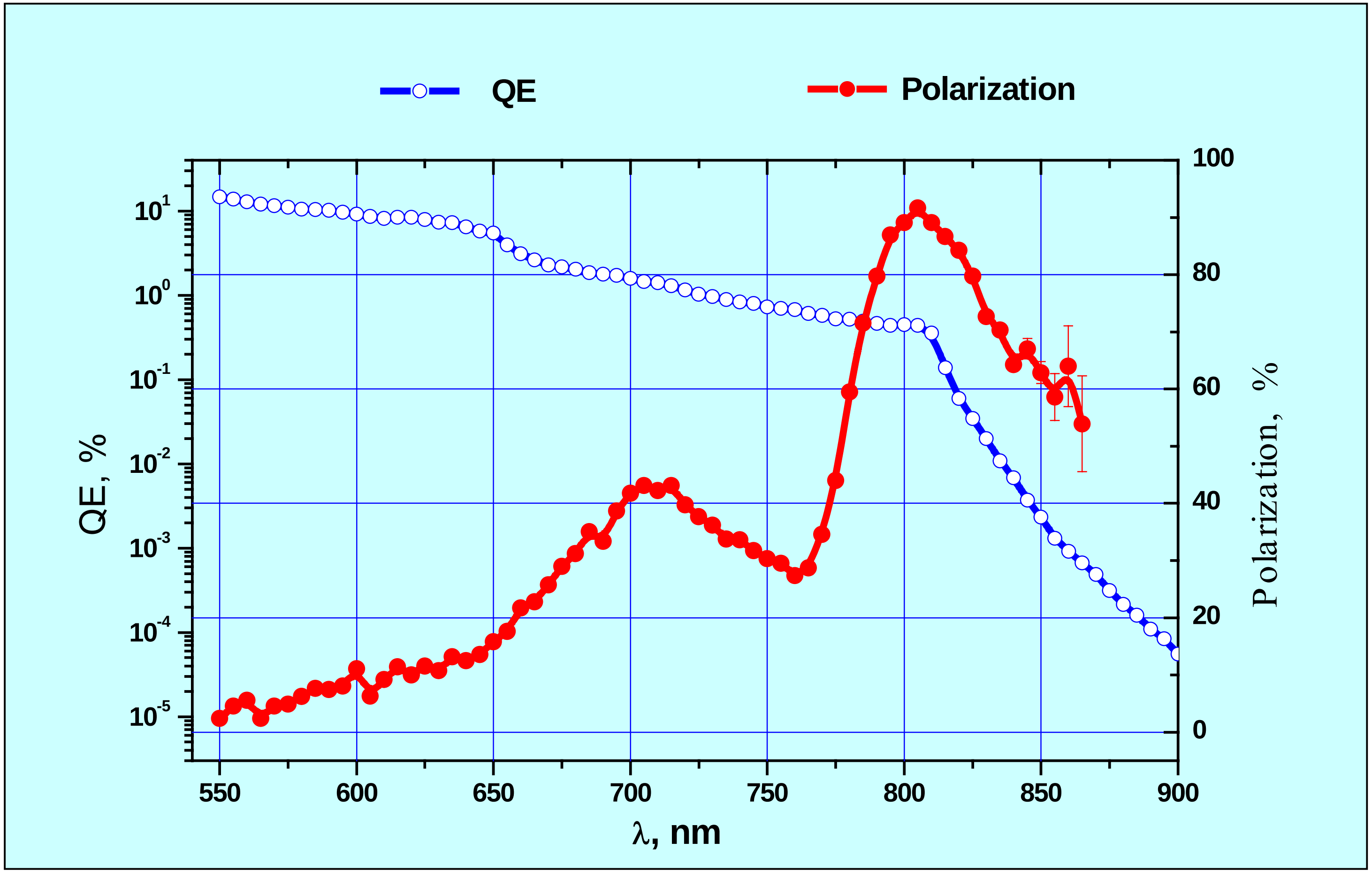
Session 9B: Topics

- Photocathode Development
  - strained super-lattice photocathode
  - gridded photocathode, pyramidal shape photocathode
- Low Emittance Beam Production
- Polarized electron source for SPLEEM
- Pol.e± □ Source for ILC
  - Polarized electron beam injector
  - Polarized positron beam production
- Pol.e- source operation
  - High average current operation
  - High current density test

SL $In_{0.155}Al_{0.2}Ga_{0.645}As$(5.1nm)/$Al_{0.36}Ga_{0.64}As$(2.3nm), **4 pairs**

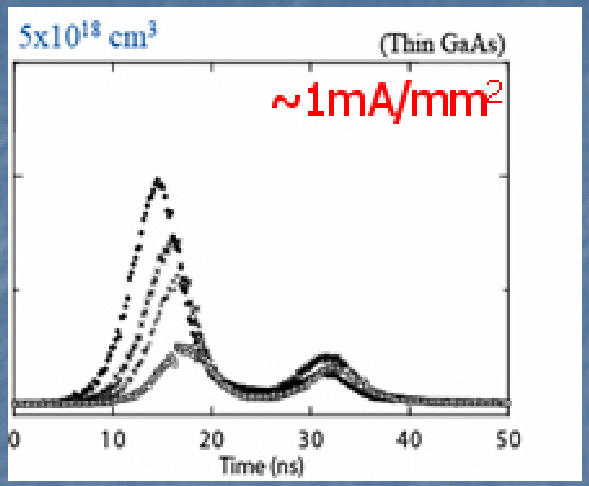
(Y. Mamaev, St.Petersburg)

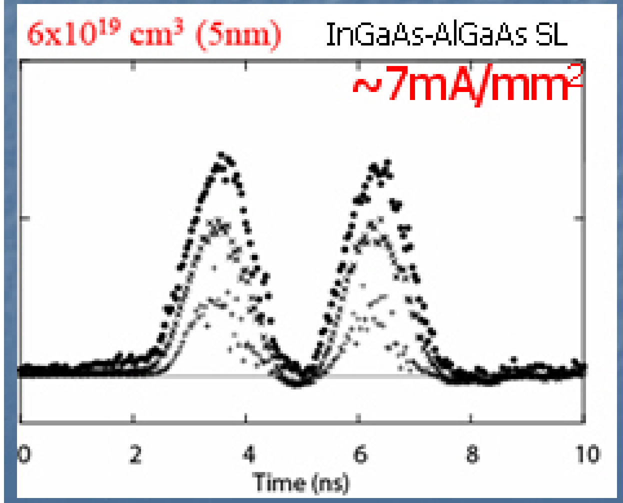




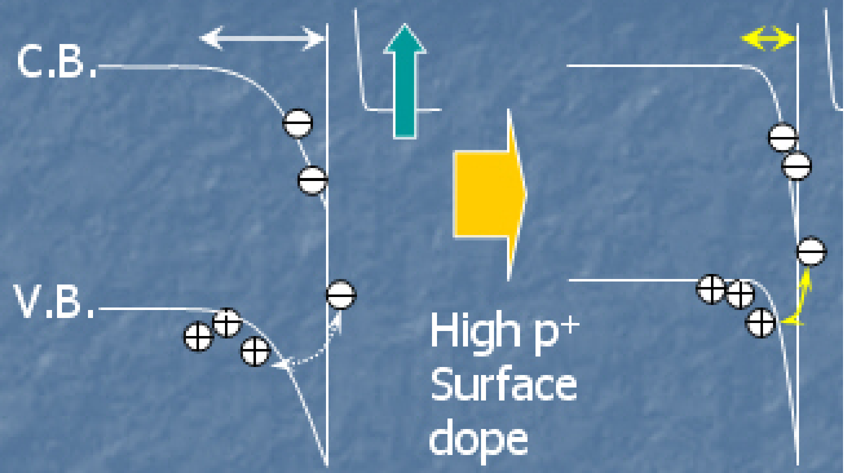
Polarization (max.) = 92%, Quantum Efficiency = 0.6%

High Surface Charge Density Superlattice Photocathodes
(M. Yamamoto, Nagoya University)





K.Togawa (2000) NIM-A 445 p118-122

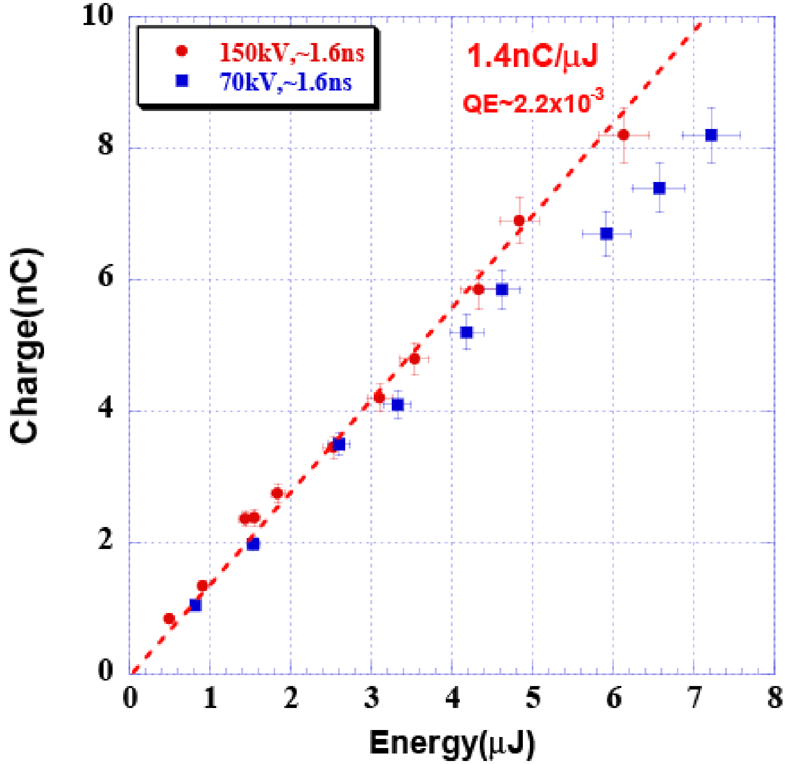


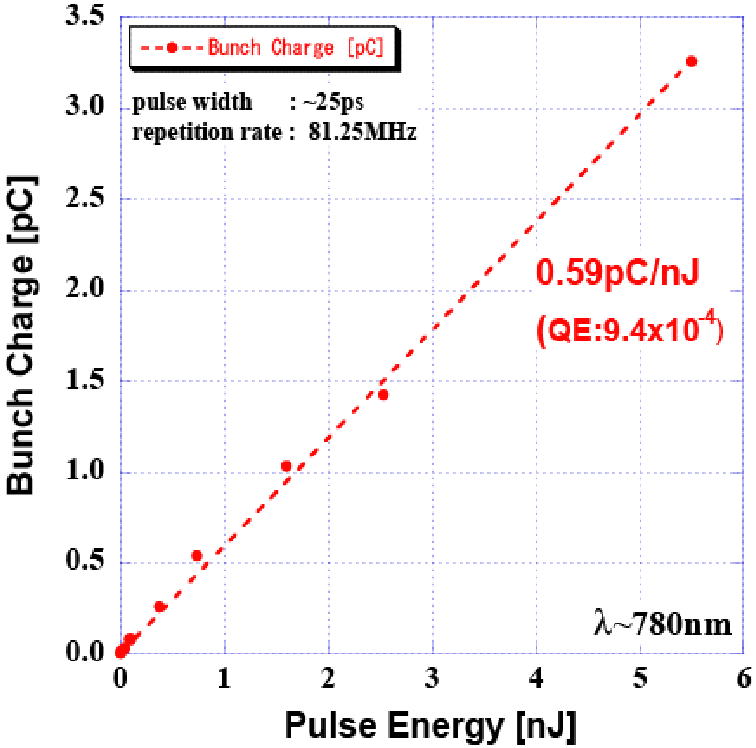
<u>Superlattice photocathode</u>:

- Surface <100 nm is GaAs
- Similar doping, e.g., Zinc
- Concern: heat => diffuses dopant

High Surface Charge Density Superlattice Photocathodes
(M. Yamamoto, Nagoya University)

GaAs/GaAsP, surface p-dope density $6x10^{19}/cm^3$

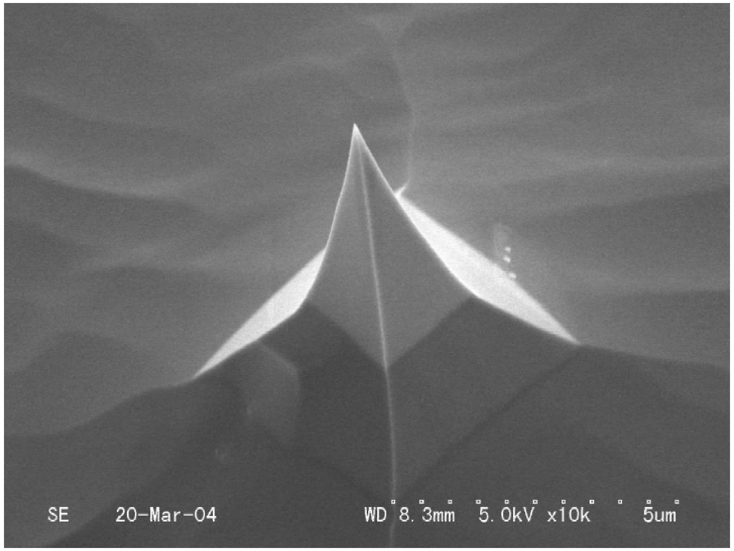


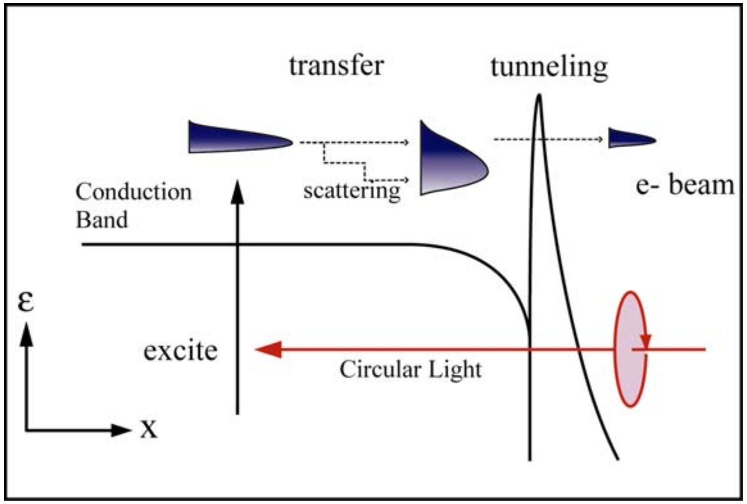


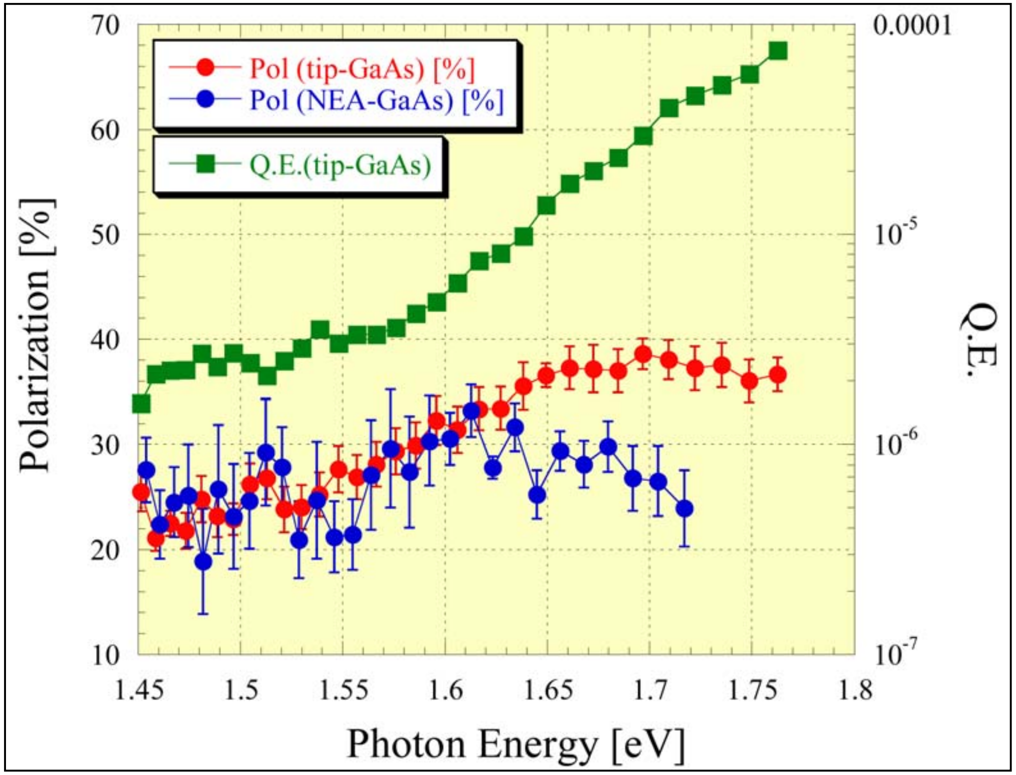
ILC-like 10's μA		JLAB-like 100's μA
8000	Bunch Charge (pC)	3.3
1600	Bunch Width (ps)	25
20	Laser Spot Size (mm)	1.6
18	Peak Current (mA/mm^2)	240

Polarized e- Extraction from a Pyramid-Shaped Photocathode

(M. Kuwahara, Nagoya University)







✓Extraction of polarized electrons by F.E.

✓Electrons extracted by F.E. have higher polarization than NEA's.

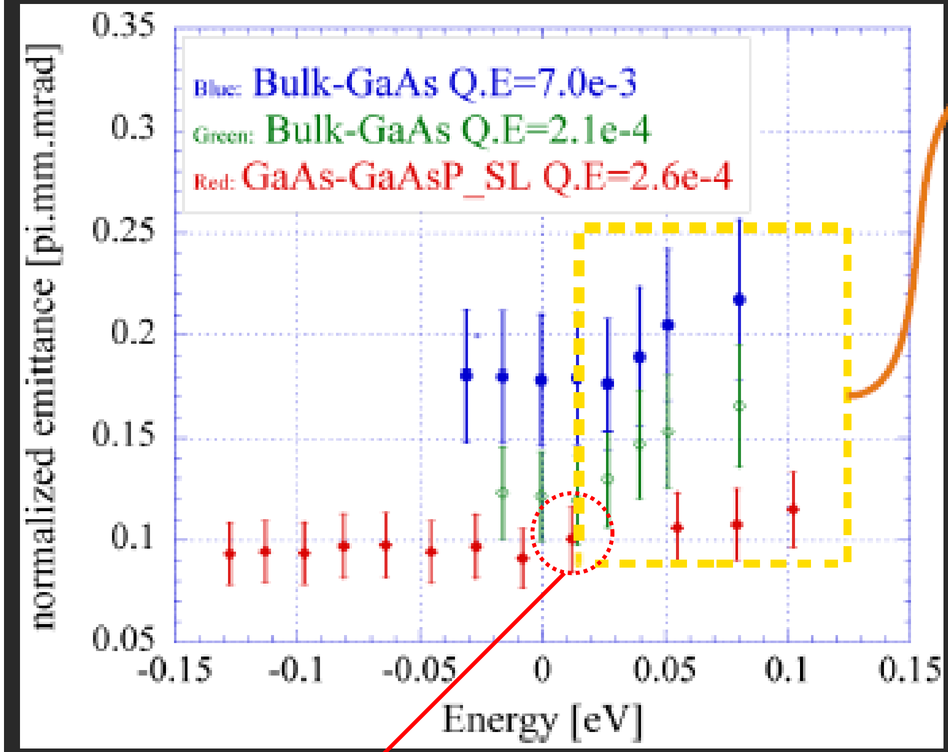
✓long lifetime compared with NEA surface.

Session 9B: Topics

- Photocathode Development
  - strained super-lattice photocathode
  - gridded photocathode, pyramidal shape photocathode
- Low Emittance Beam Production
- Polarized electron source for SPLEEM
- Pol.e± Source for ILC
  - Polarized electron beam injector
  - Polarized positron beam production
- Pol.e- source operation
  - High average current operation
  - High current density test

Low Emittance Beam from GaAs-GaAsP superlattice photocathode
(N. Yamamoto, Nagoya University)

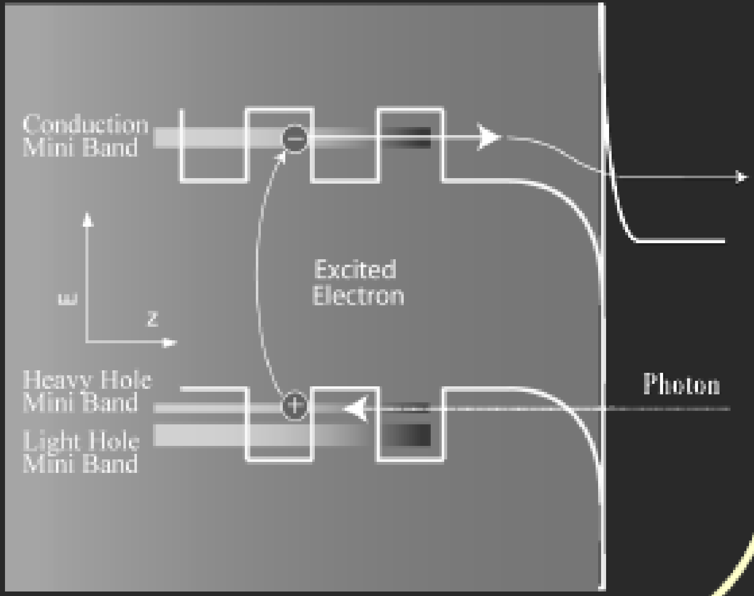
emittance vs laser energy from band gap



ε_{rms} = 0.096±0.015 π.mm.mrad

At superlattice photocathode, the increase of emittance is lower.

This effect is explained by the joint density of state(JDOS) model*.

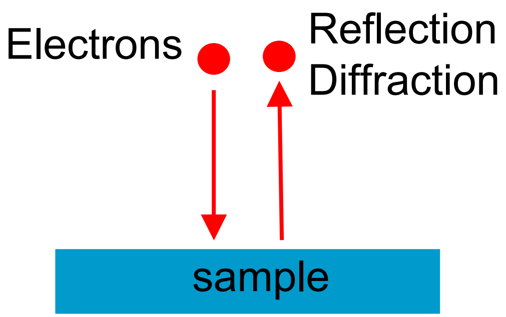


Session 9B: Topics

- Photocathode Development
  - strained super-lattice photocathode
  - gridded photocathode, pyramidal shape photocathode
- Low Emittance Beam Production
- Polarized electron source for SPLEEM
- Pol.e□Source for ILC
  - Polarized electron beam injector
  - Polarized positron beam production
- Pol.e- source operation
  - High average current operation
  - High current density test

LEEM: Low Energy Electron Microscopy

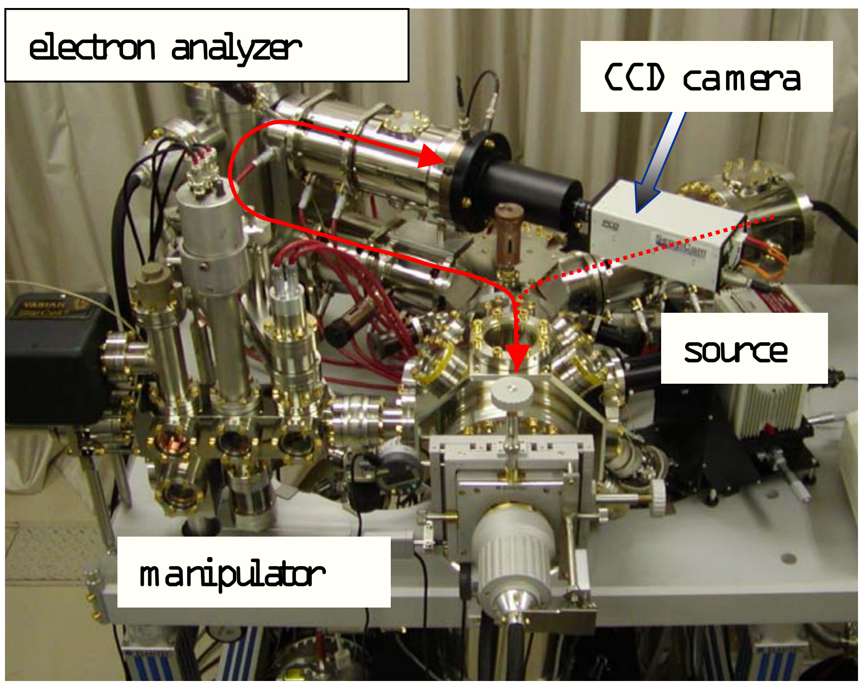
(T. Yasue, Osaka Electro-Commmunications University)

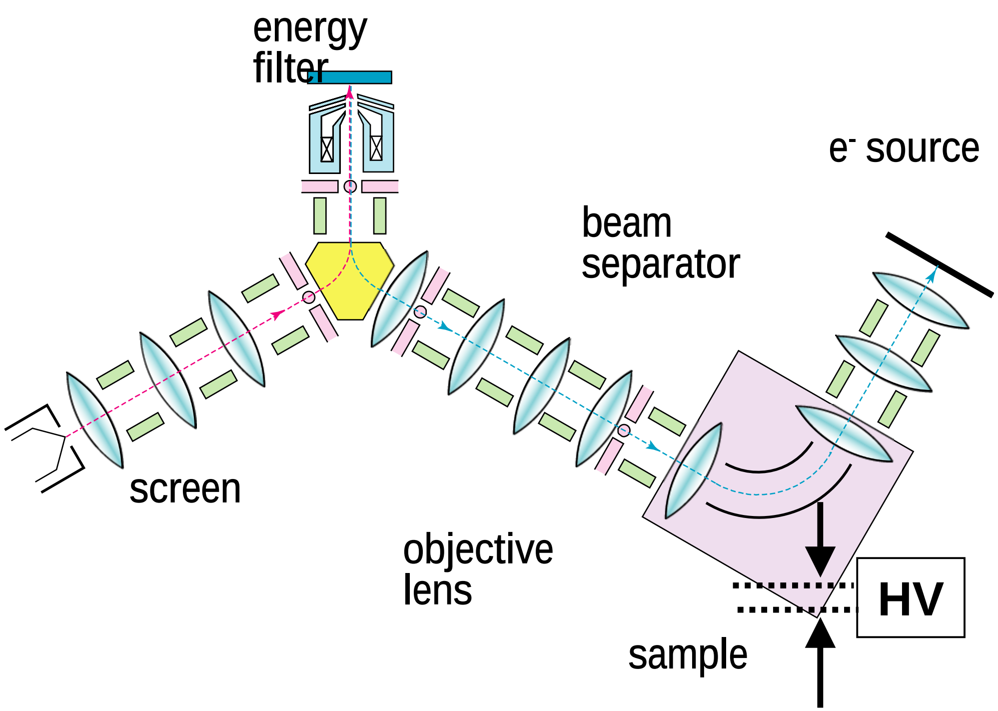


Low energy electrons: strong interaction with surfaces

- **relatively high reflectivity**
- **small penetration depth**

➡ ***SURFACE SENSITIVE***

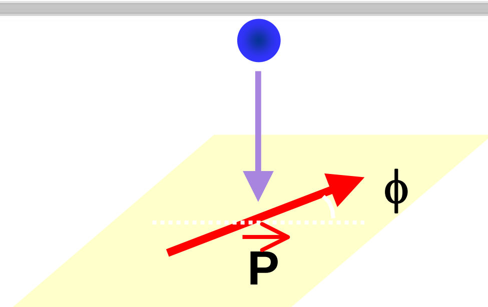




SPLEEM: Spin Polarized LEEM

(T. Yasue, Osaka Electro-Commmunications U. & S. Okumi, Nagoya U.)

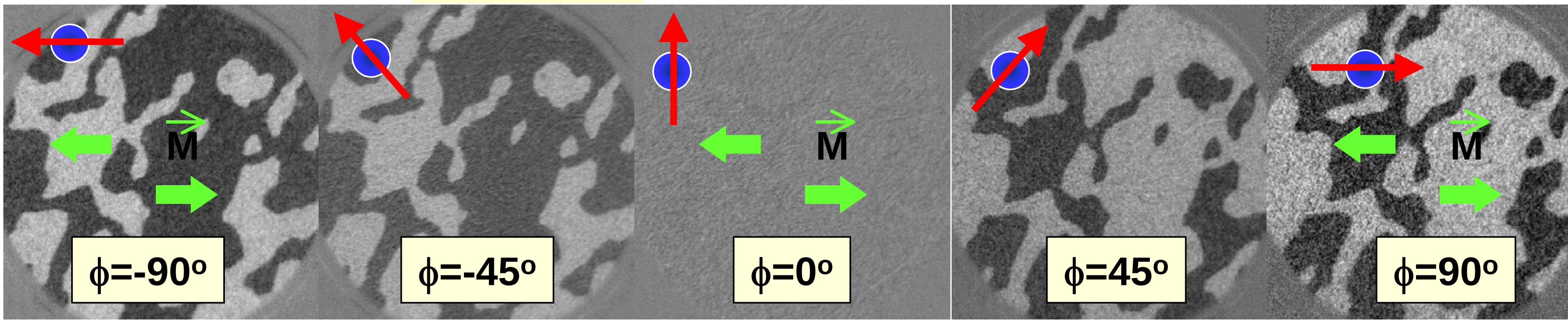
- Co/W(110)
- 3.8eV
- FOV=25mm
- in-plane

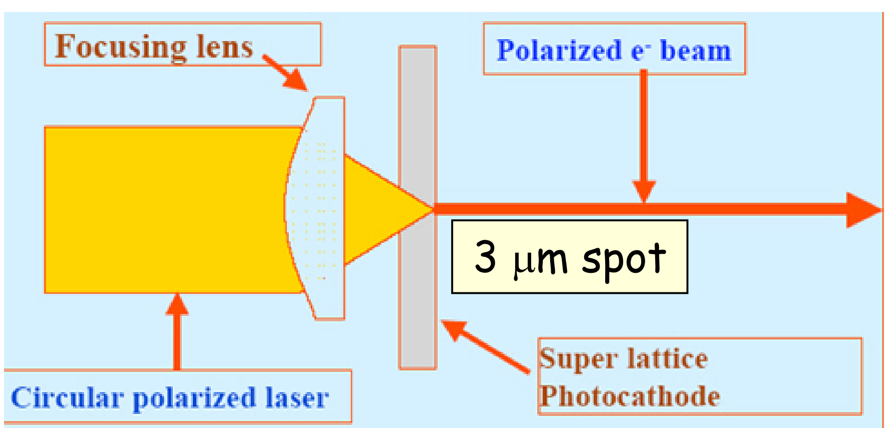


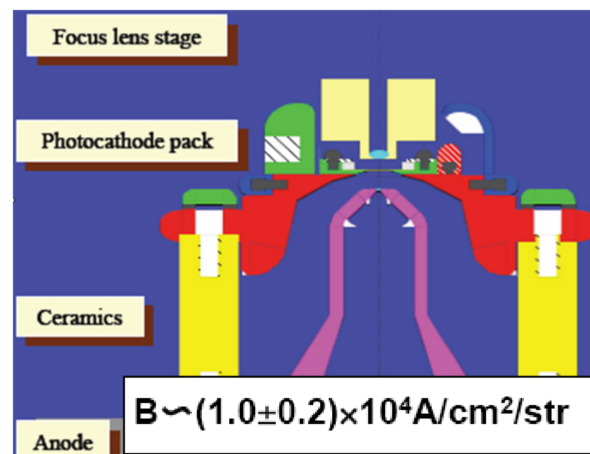
CONTRAST: P·M

P // M: maximum (minimum)

P ⊥ M: 0



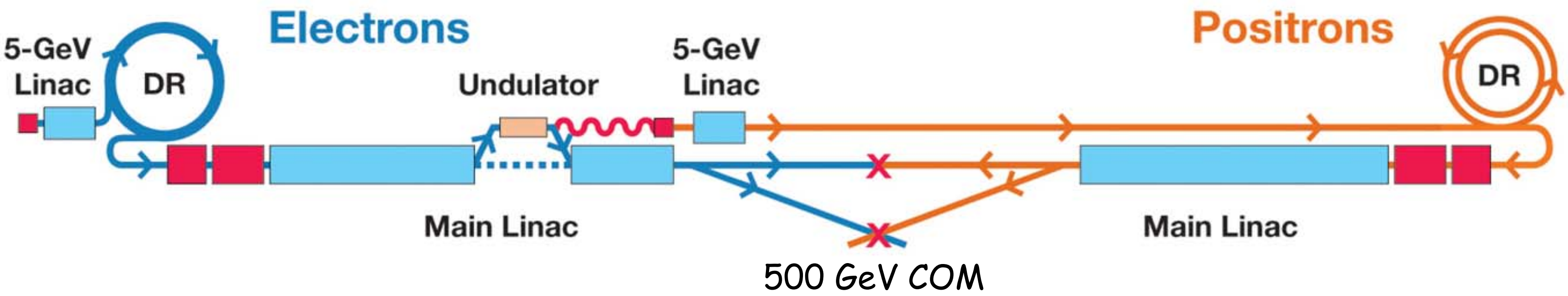


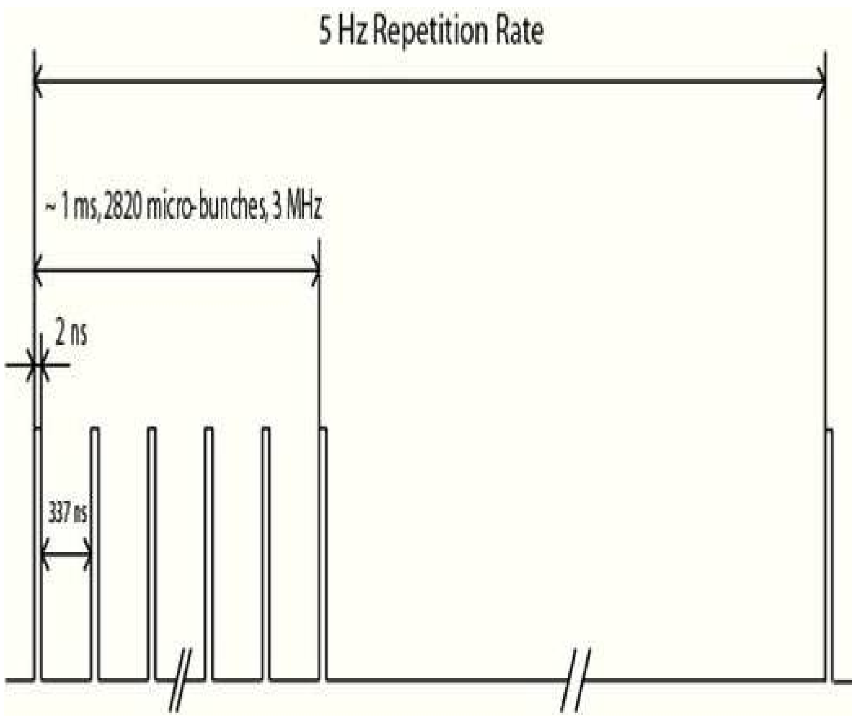


Session 9B: Topics

- Photocathode Development
  - strained super-lattice photocathode
  - gridded photocathode, pyramidal shape photocathode
- Low Emittance Beam Production
- Polarized electron source for SPLEEM
- Pol.e± Source for ILC
  - Polarized electron beam injector
  - Polarized positron beam production
- Pol.e- source operation
  - High average current operation
  - High current density test

International Linear Collider
(Jym Clendenin, SLAC)

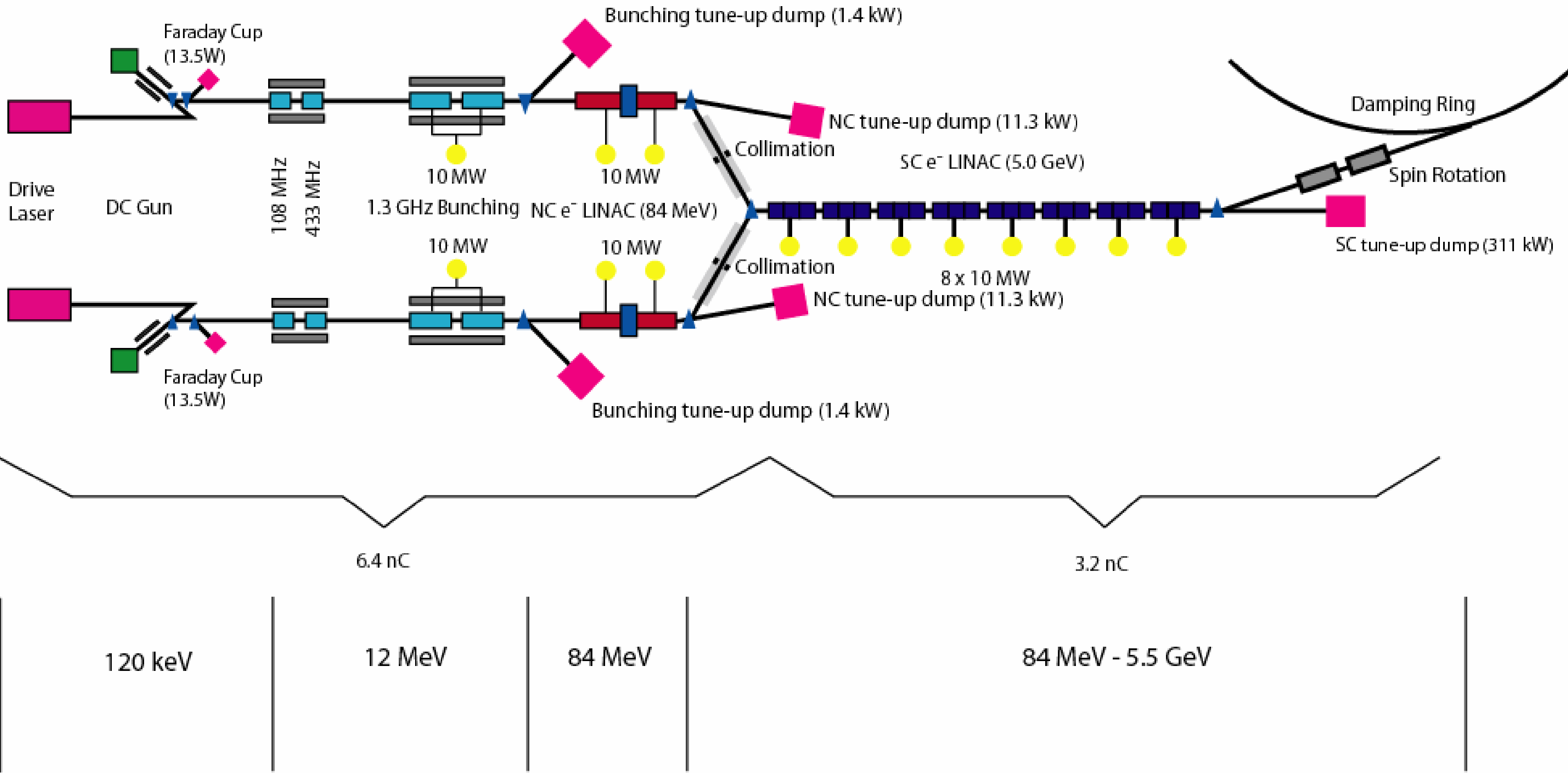




Parameter	Units	SLC	ILC
Electrons per bunch	nC	16	6.4
Bunches per pulse	#	2	2820
Microbunch rep rate	MHz	17	3
Pulse rep rate	Hz	120	5
Cathode area	cm^2	3	TBD
Cathode bias	kV	-120	TBD
Bunch length	ns	2	TBD
Gun to SHB1 drift	cm	150	TBD
$e_{n,rms,gun}$ (fm EGUN)	10^{-6} m	15	20

Polarized Electron Injector Layout

(Axel Brachmann, SLAC)



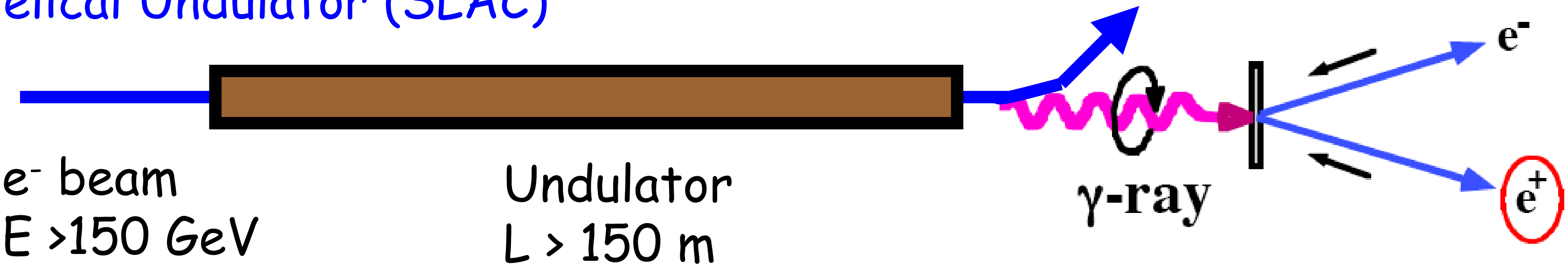
Polarized Electron Injector Layout
(Axel Brachmann, SLAC)

- **Laser Development**
  - Laser system beyond state of the art
  - Challenge is 3 MHz amplification (P_{ave} ~ 100 mW, P_{burst} ~15 W)

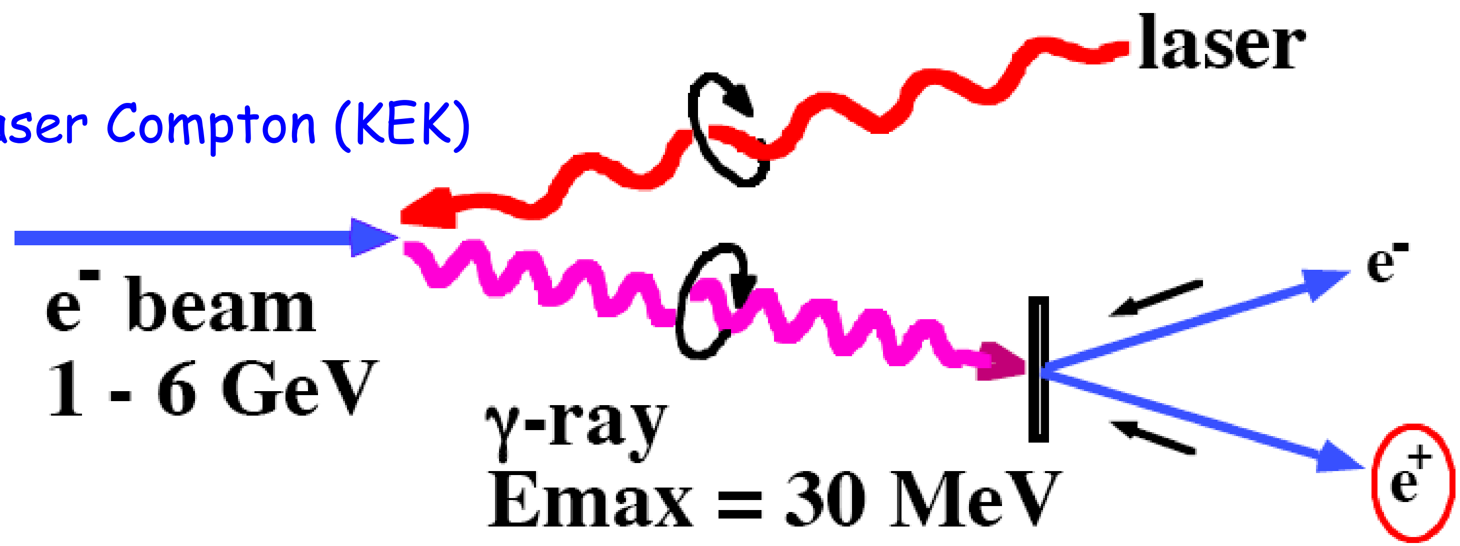
- **Photocathode Development**
  - Demonstrate performance with high P_{burst}
  - Combination of high-QE & low-SCL (doping), while high-P

- **Gun Development**
  - Baseline Design: 120 kV SLC Gun
  - Higher voltage will reduce (SH) bunching timing requirements
  - Polarized RF gun: R&D effort to explore feasibility

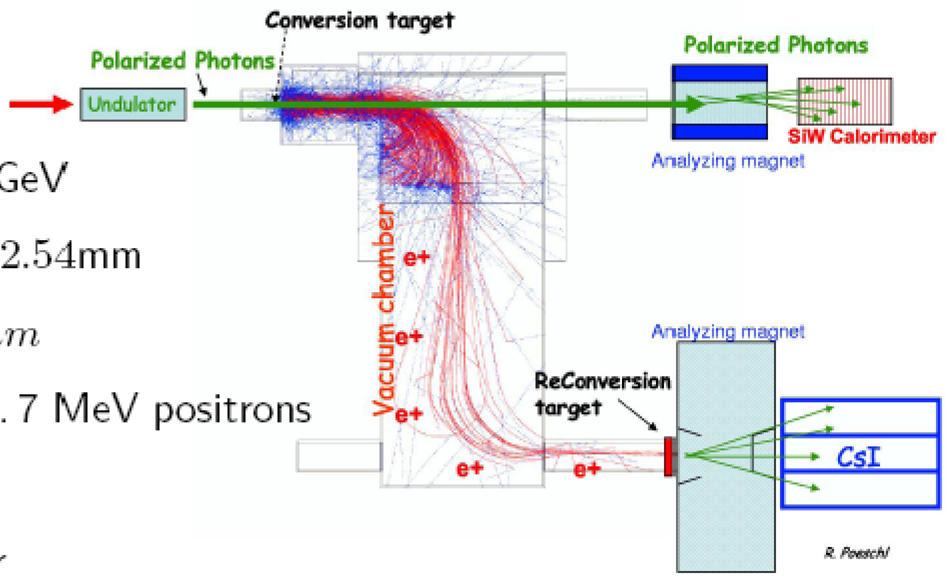
(1) Helical Undulator (SLAC)



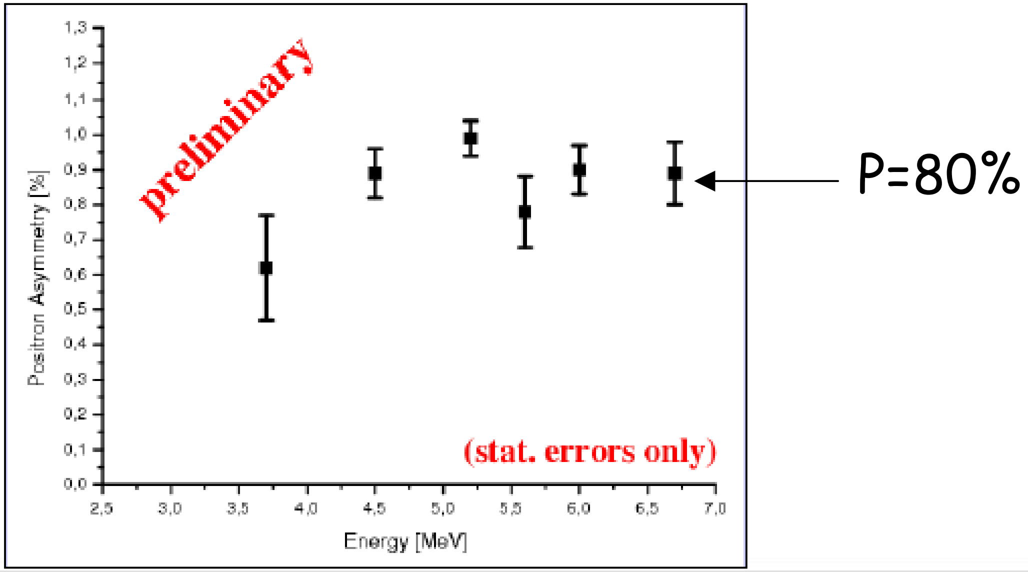
(2) Laser Compton (KEK)



The E166 Experiment at SLAC
(P. Shuler, DESY)

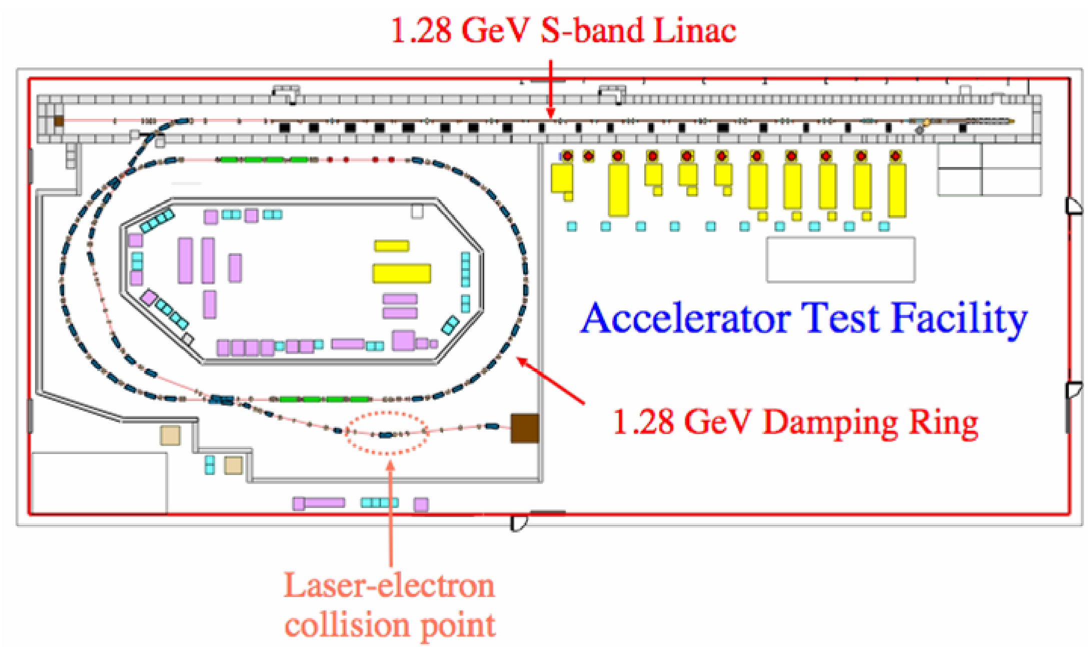


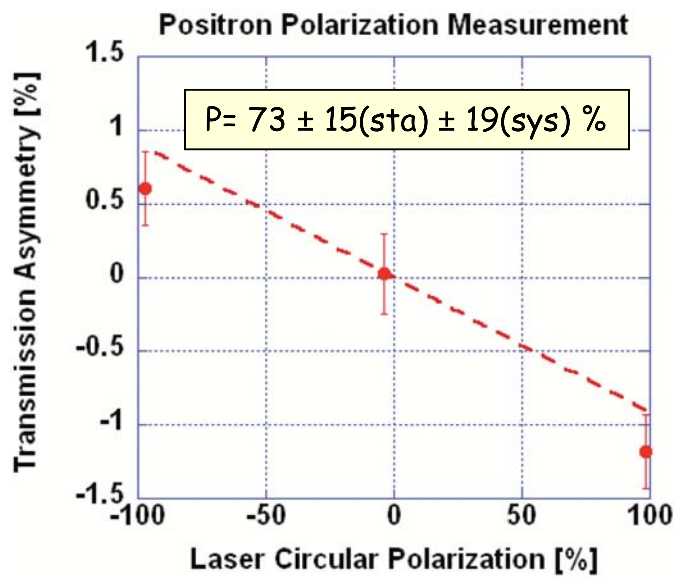
- initial e^- beam at 46.6 GeV
- helical undulator period 2.54mm
- W target $.5\,X_0 = 1.75mm$
- spectrometer selects 3…7 MeV positrons
- reconversion to photons
- magnetised iron analyzer
- CsI calorimeter

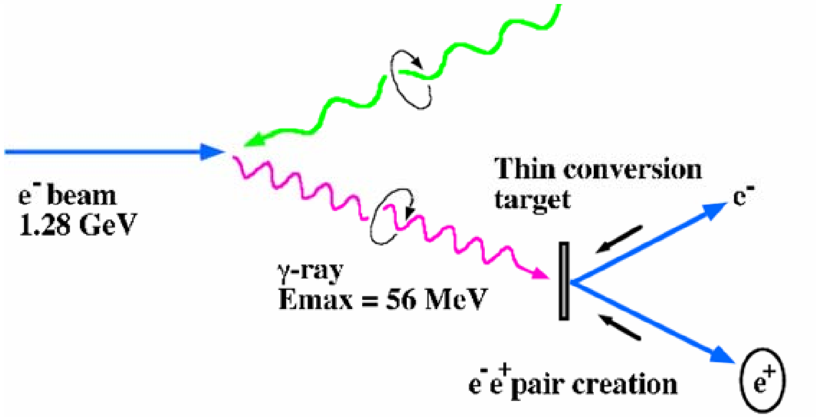


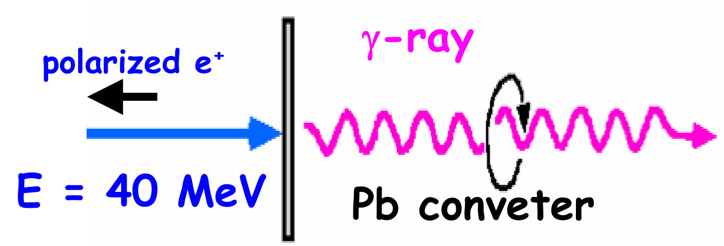
Accelerator Test Facility for ILC at KEK

(T. Omori, KEK)



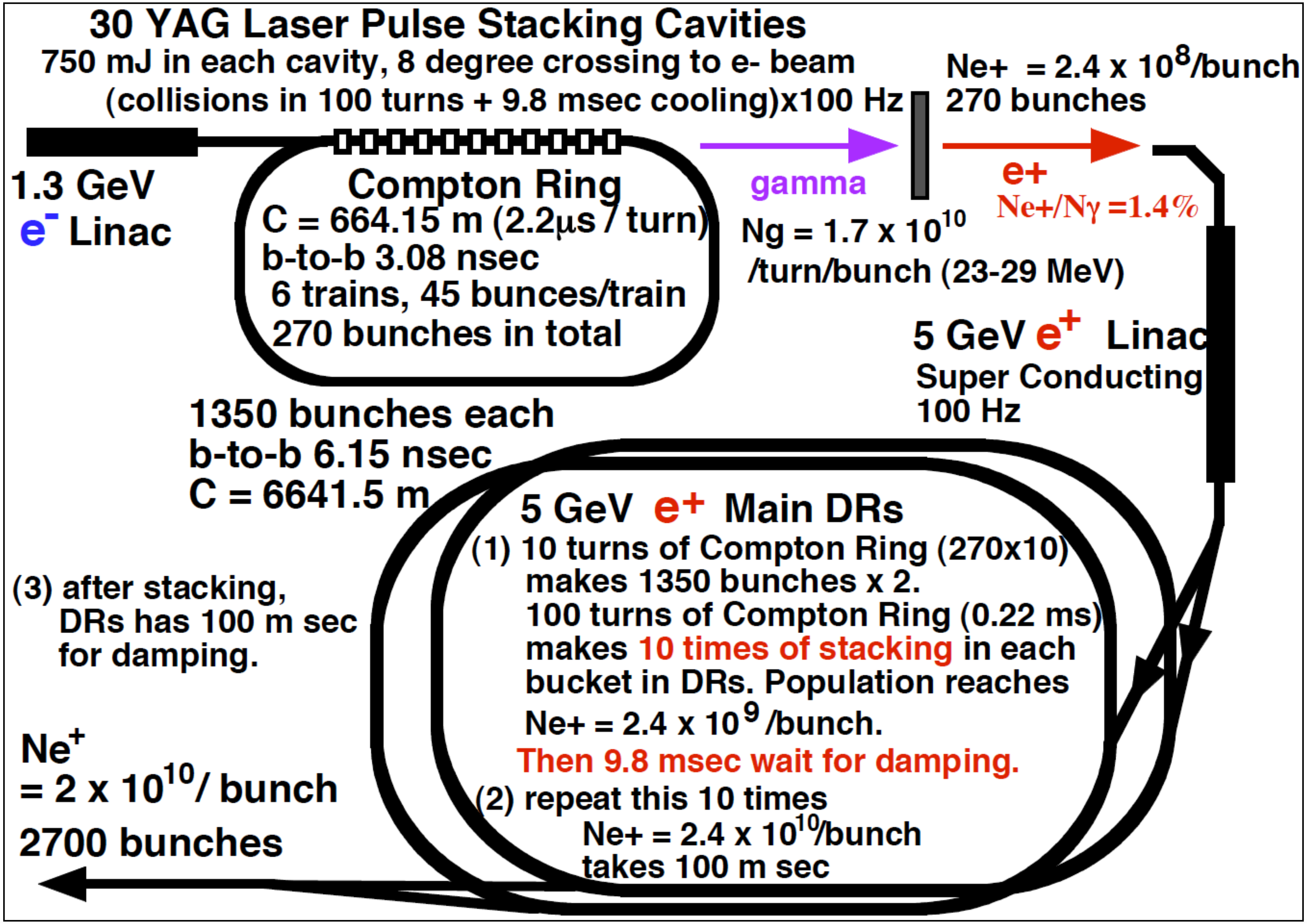






M. Fukuda et al., PRL 91(2003)164801

Compton Cavity Collaboration – Dedicated e- Ring
(T. Omori, KEK)



Session 9B: Topics

- Photocathode Development
  - strained super-lattice photocathode
  - gridded photocathode, pyramidal shape photocathode
- Low Emittance Beam Production
- Polarized electron source for SPLEEM
- Pol.e□Source for ILC
  - Polarized electron beam injector
  - Polarized positron beam production
- Pol.e- source operation
  - High average current operation
  - High current density test

Further Measurements of Photocathode Operational Lifetime at Beam Intensity > 1mA with the NEW 100 kV DC GaAs Photogun

J. Grames, M. Poelker, P. Adderley, J. Brittian, J. Clark,
J. Hansknecht, E. Pozdeyev, M. Stutzman, K. Surles-Law

Goal: Deliver high average current (> 1mA) and high polarization (> 80%) with long photocathode operational lifetime in support of new accelerator initiatives.

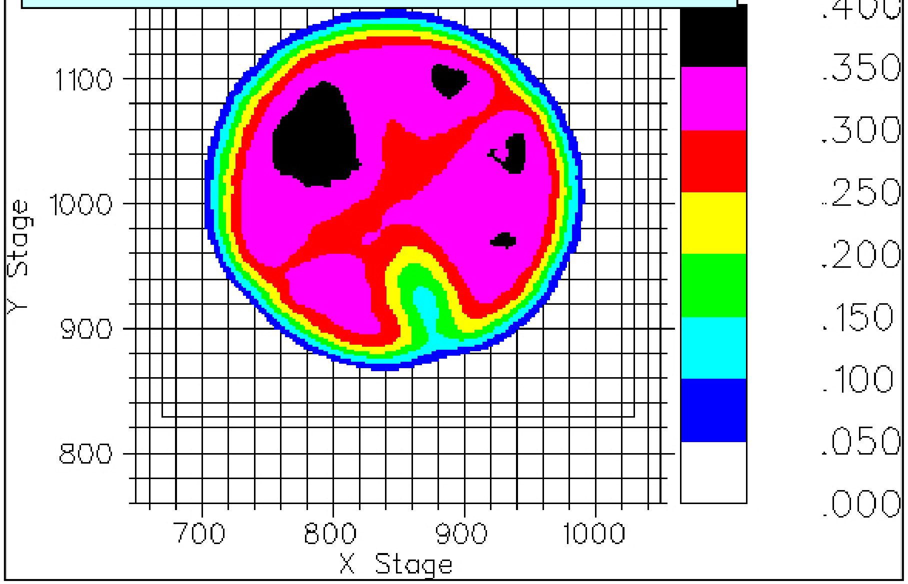
Enhance our understanding of photocathode decay mechanism. Will undoubtedly allow us to improve existing polarized guns operating at lower average current and unpolarized guns at milliAmp beam currents (e.g., Lightsources).

CEBAF => busy, productive NP program

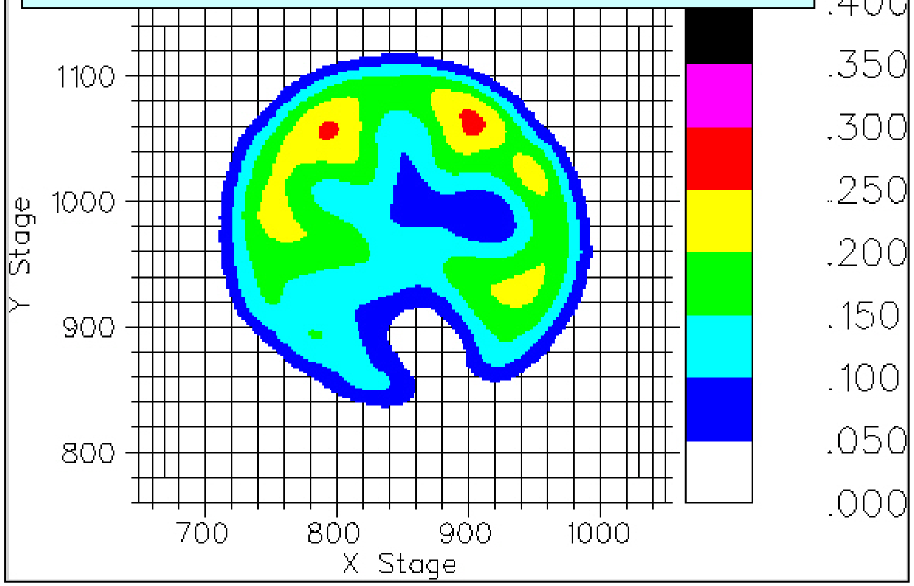
- 35 weeks/year
- 100 μA at 85% polarization is fairly routine
- One photocathode operates for year(s), and three or four activations
- 2-3 Users simultaneously; one is always Parity Violation experiment

Photocathode Lifetime limited by ion back-bombardment.

September 2006 Activation (#5)



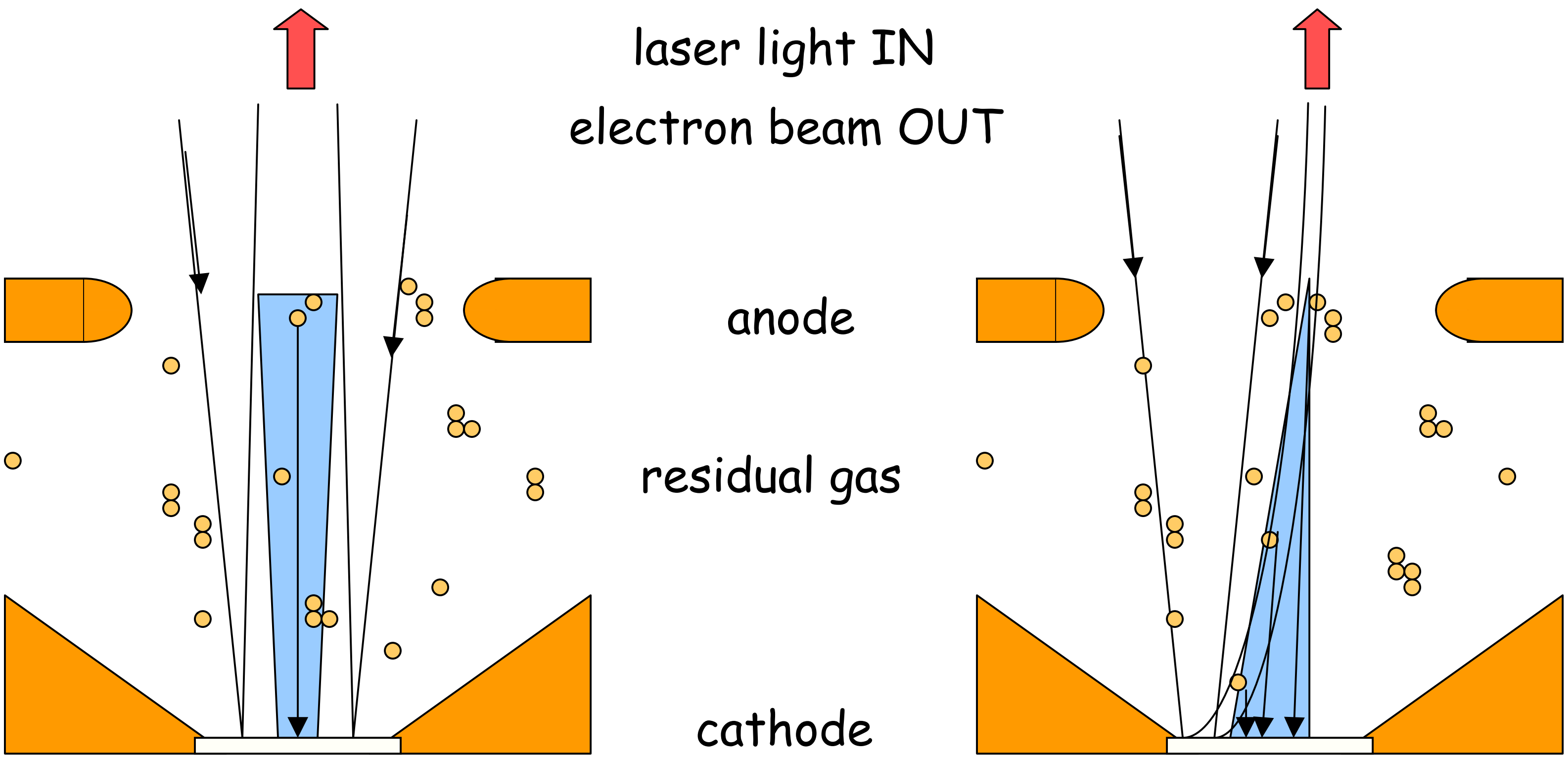
Yesterday, the “tired” photocathode



Ion Back-Bombardment

Ions accelerated & focused to electrostatic center

We don't run beam from electrostatic center

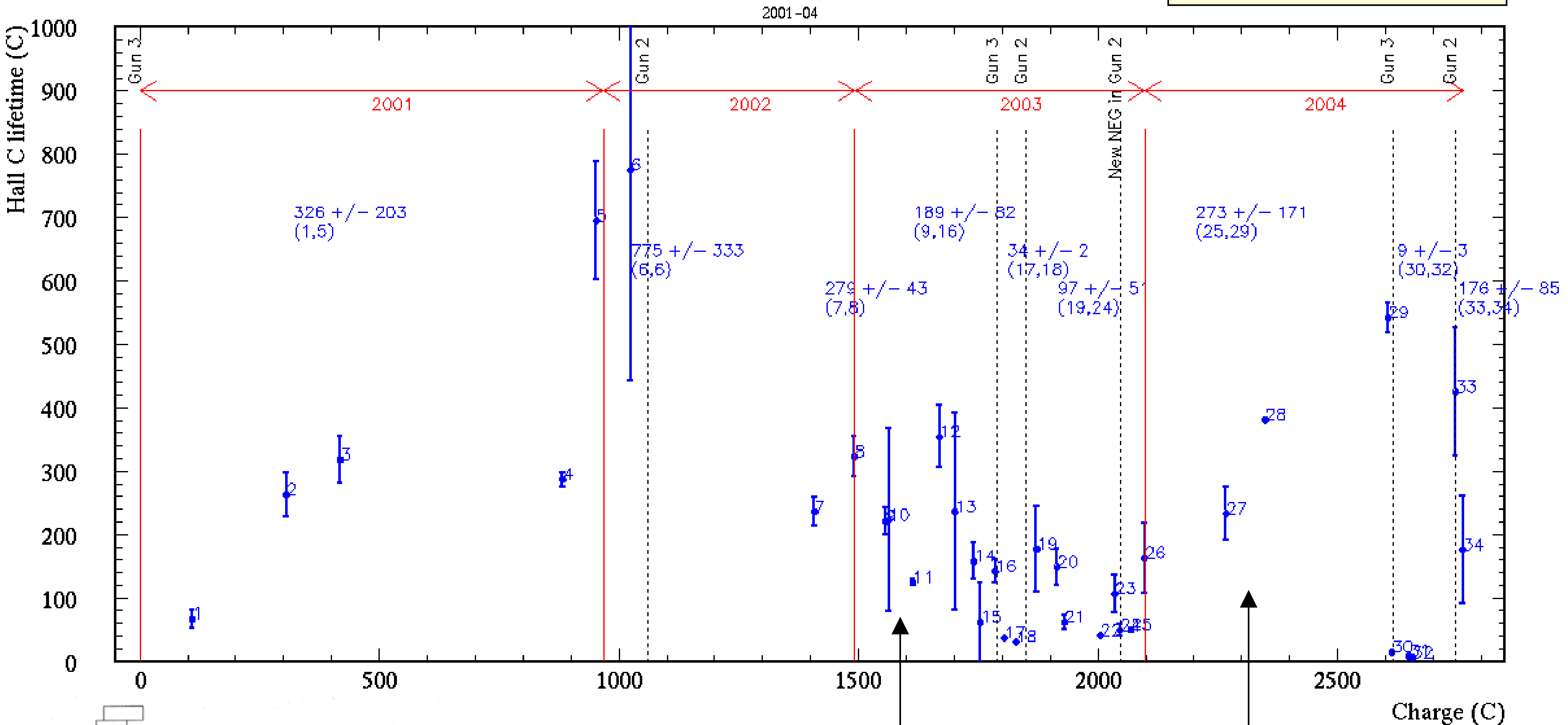


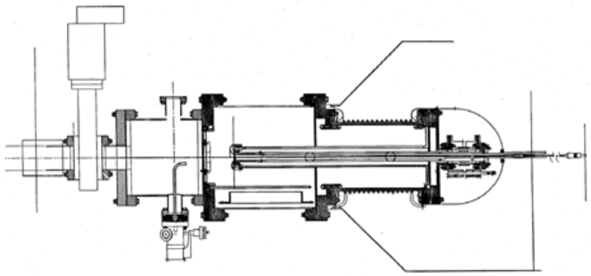
Which ions more problematic?

QE trough to electrostatic center

CEBAF Gun Charge Lifetime (2001-2004)

Data compiled by M. Baylac

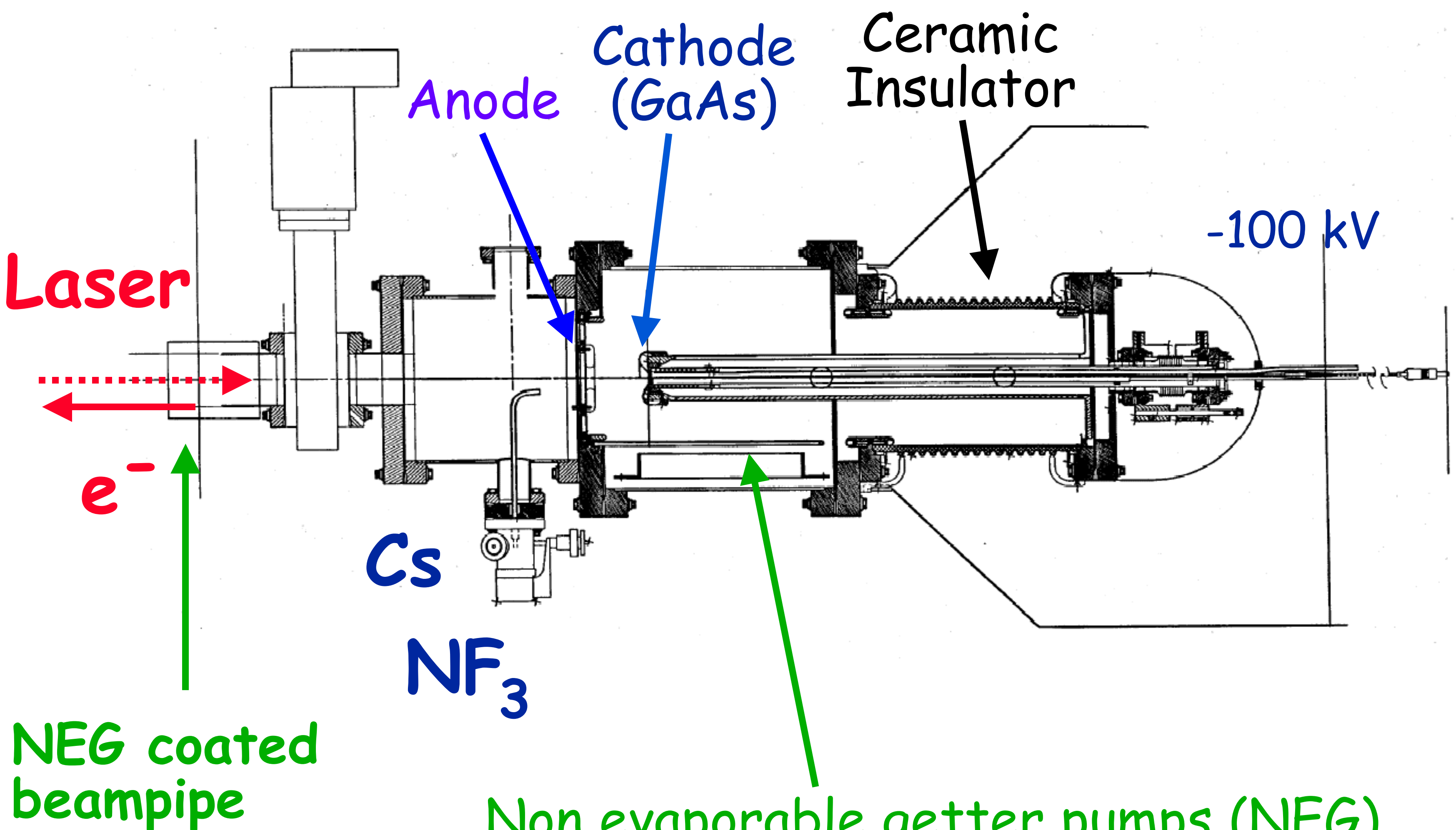




Charge Lifetime Steadily Decreasing

NEG replacement Summer 2003 improves lifetime

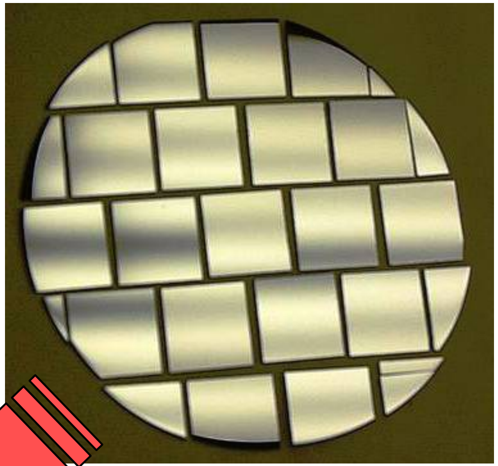
Present JLab Polarized Electron Gun



4,000 liter/s pump speed ⇒ 5E-12 Torr

The Wafer…

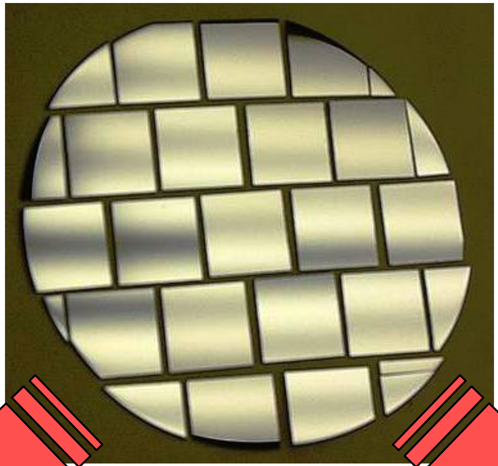
Wafer from vendor



Stalk Mounted

Paradigm Shift (Peggy Style => Load Lock Gun)

Wafer from vendor



Stalk Mounted

Puck Mounted

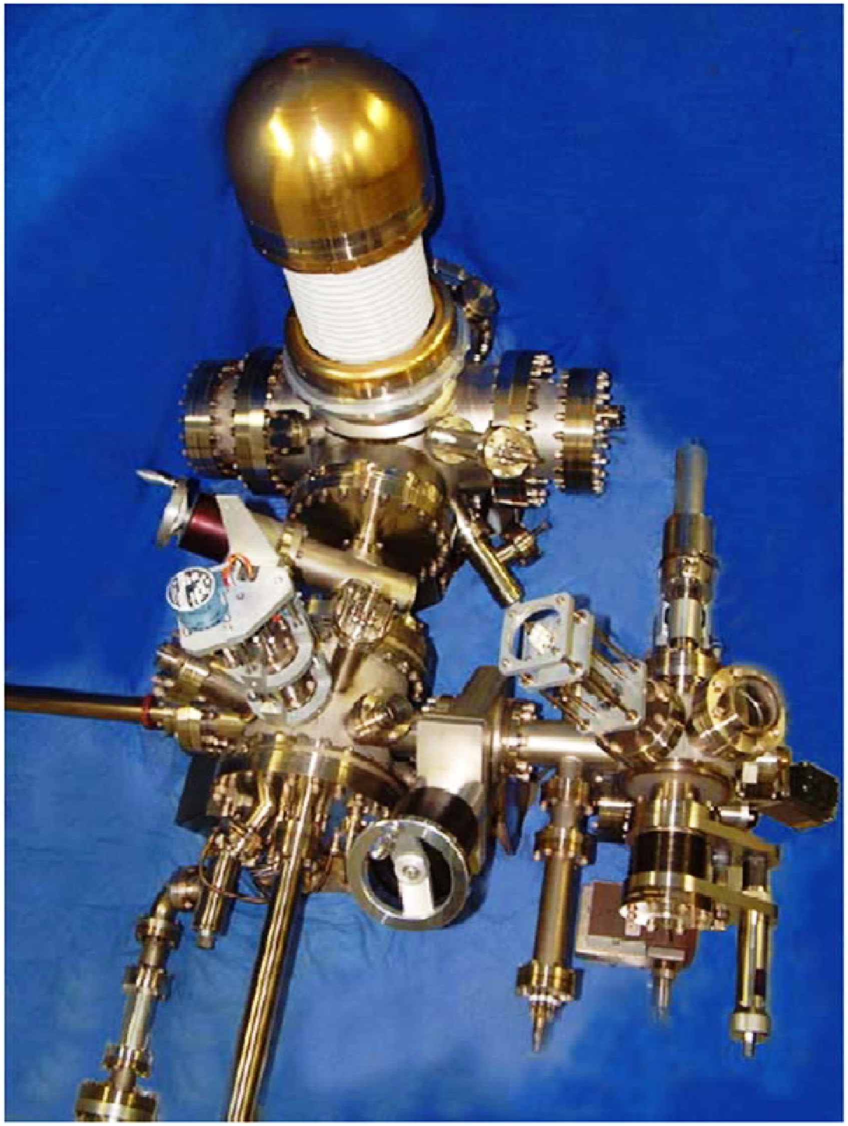
BTLLPEG Operation (2003-2006)

3 Chambers

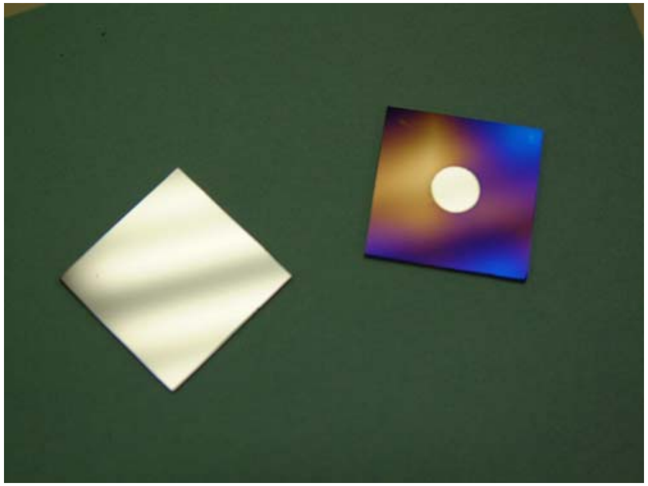
- Load/Hydrogen/Heat
- Prepare NEA surface
- High Voltage, Good Vacuum

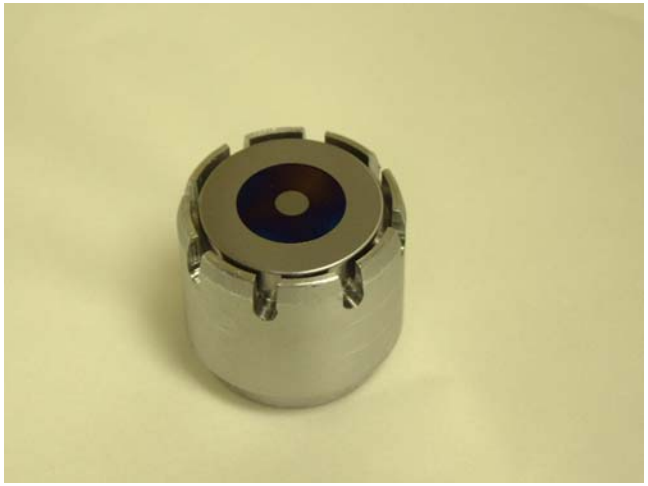
Photocathode Lifetime Test Bed

- Low-P bulk GaAs
- High QE (15-20%) => mA's
- 200 C/day vs. 20 C/day

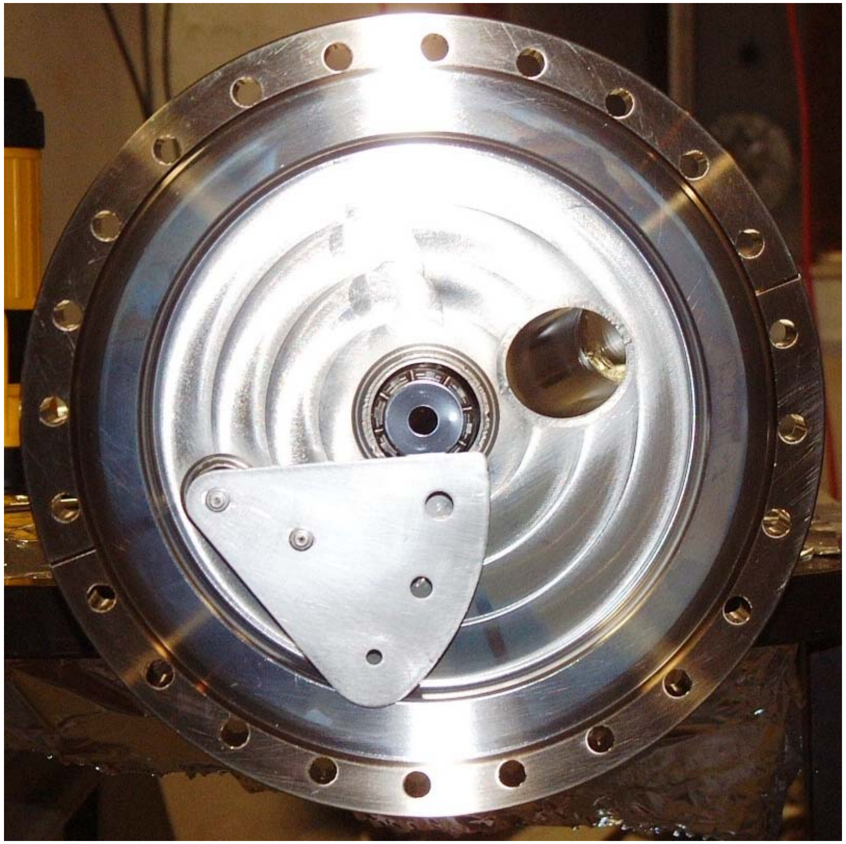


Improvements limiting the active area

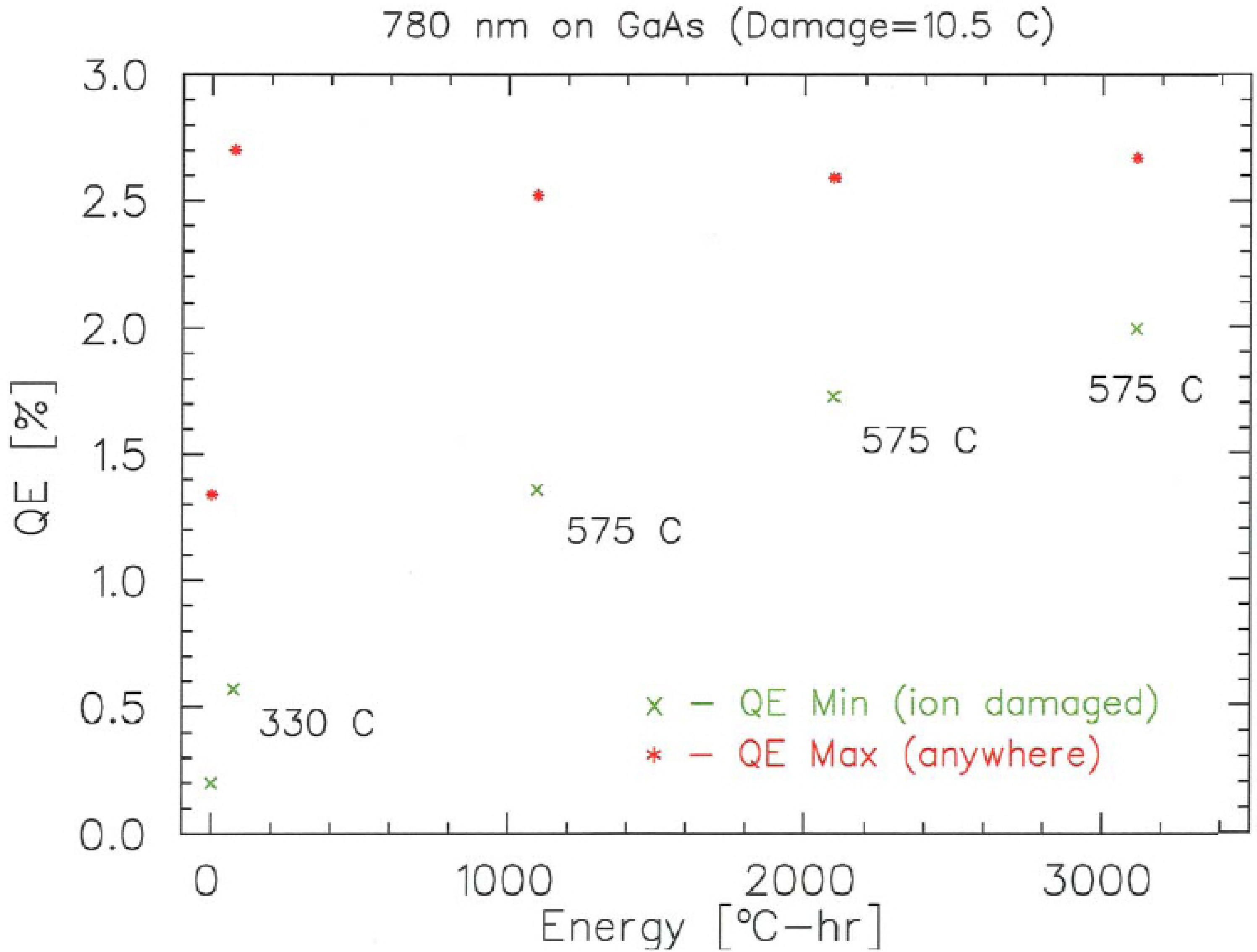




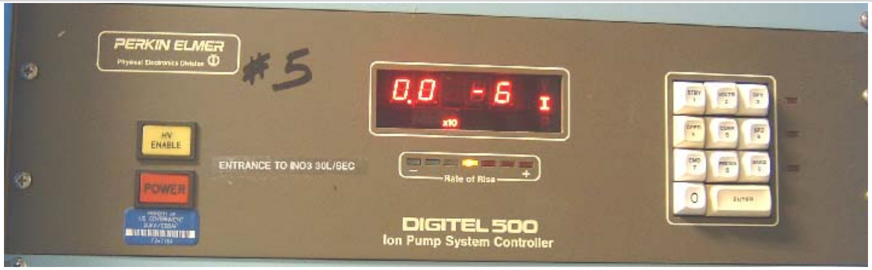
No more hydrogen cleaning
Study one sample without removal

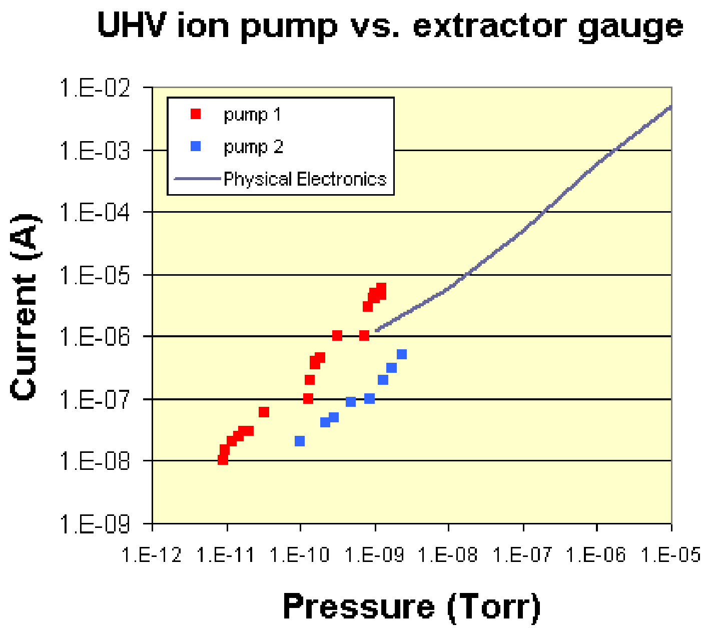


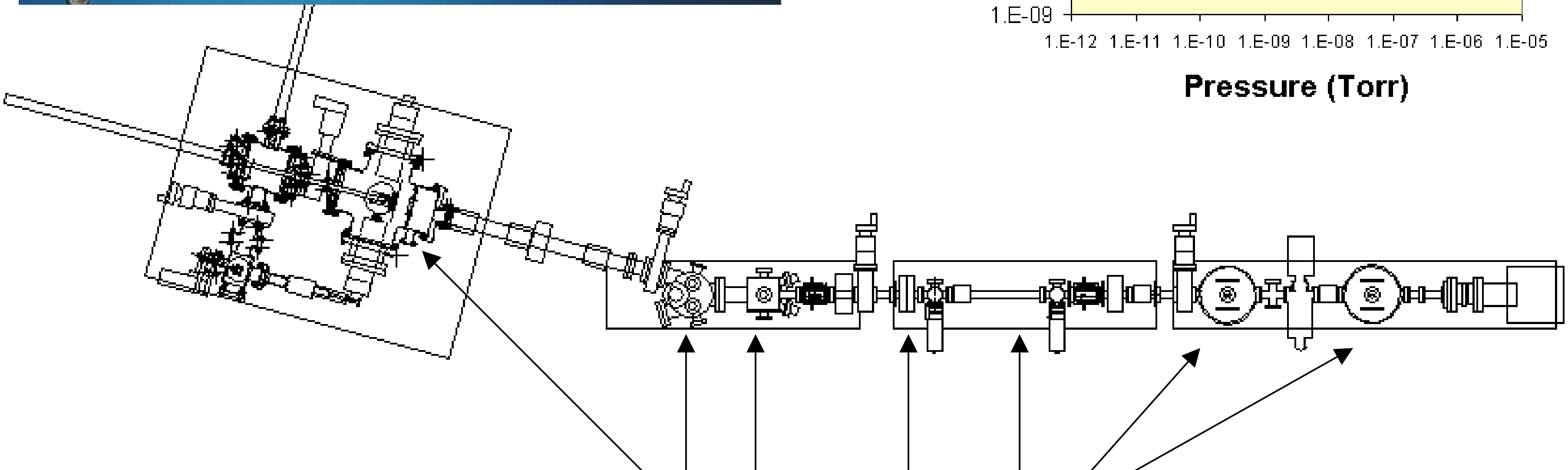
Improvements restoring ion damage site



Improvements to monitor gun & beamline pressure

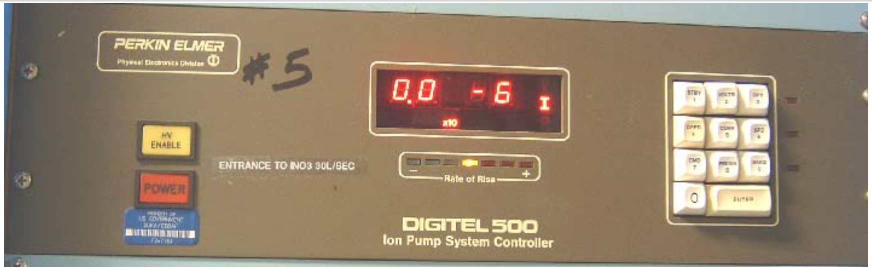


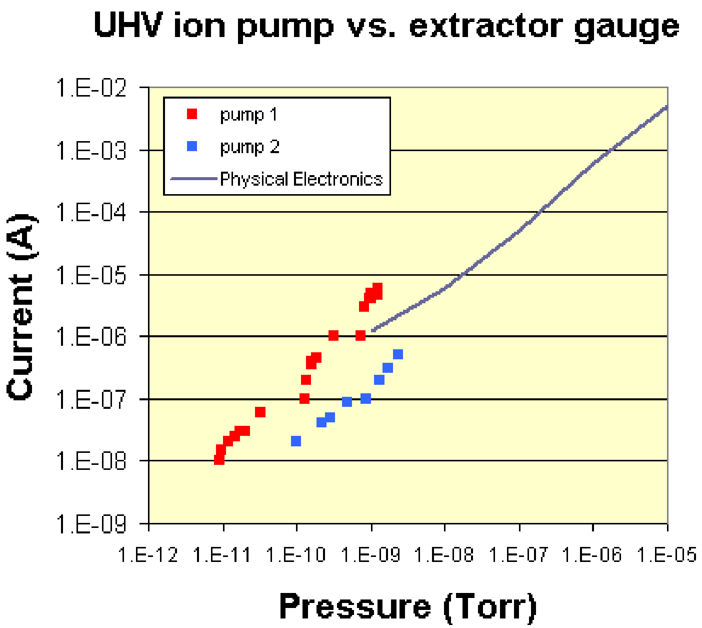


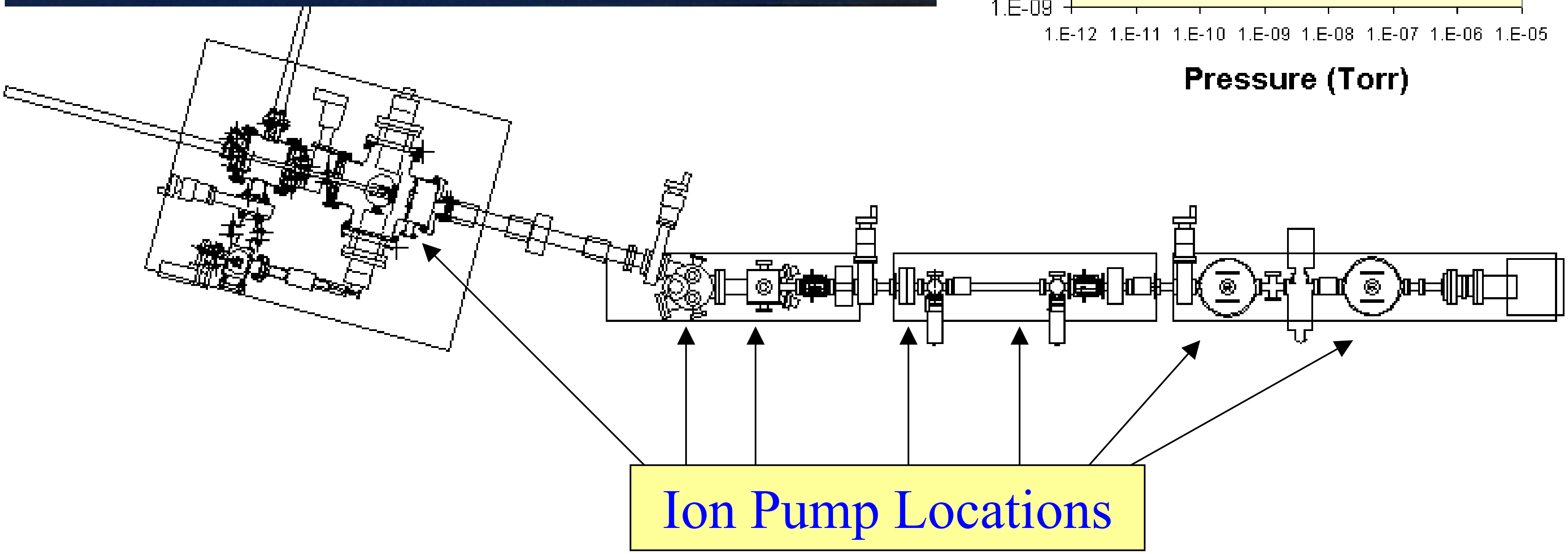


Ion Pump Locations

Improvements to monitor gun & beamline pressure







Photocathode Lifetime Studies & Operation (2003-2006)

We've learned about photocathode lifetime…

- vs. gun & beamline pressure (leaks, pumping, gauging)
- vs. laser (spot size, position, reflections, power levels)
- vs. GaAs preparation (active area, cleaning)
- vs. beam handling (optics, orbits, beam losses)

We've learned about functionality of a Load Lock gun…

- Round pucks + gravity = rolling
- Manipulator alignment + bake-outs
- Activation, heating, cooling
- Sensitivity of manipulators to bake temperature
- Multiple photocathodes > 1 photocathode

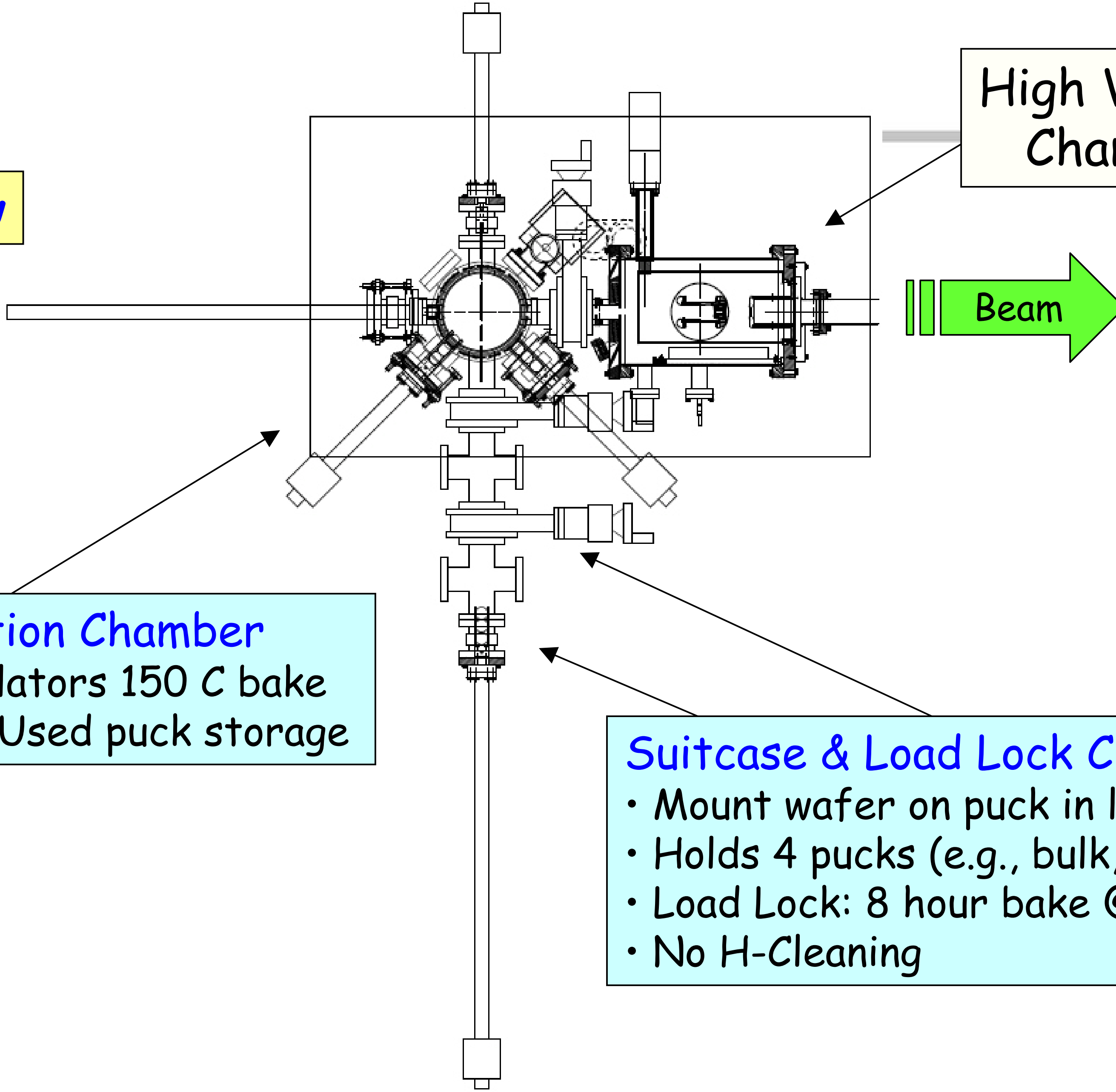
Work mainly presented at workshops & recorded in proceedings…

NEW Load Lock PhotoGun for CEBAF

What's next (really, now!)...

- Improve gun vacuum
- Block ionized gas from the photocathode
- Load multiple photocathodes with the "suitcase"
- Design-out the handful of little & big "features"
- Transfer technology to the CEBAF program

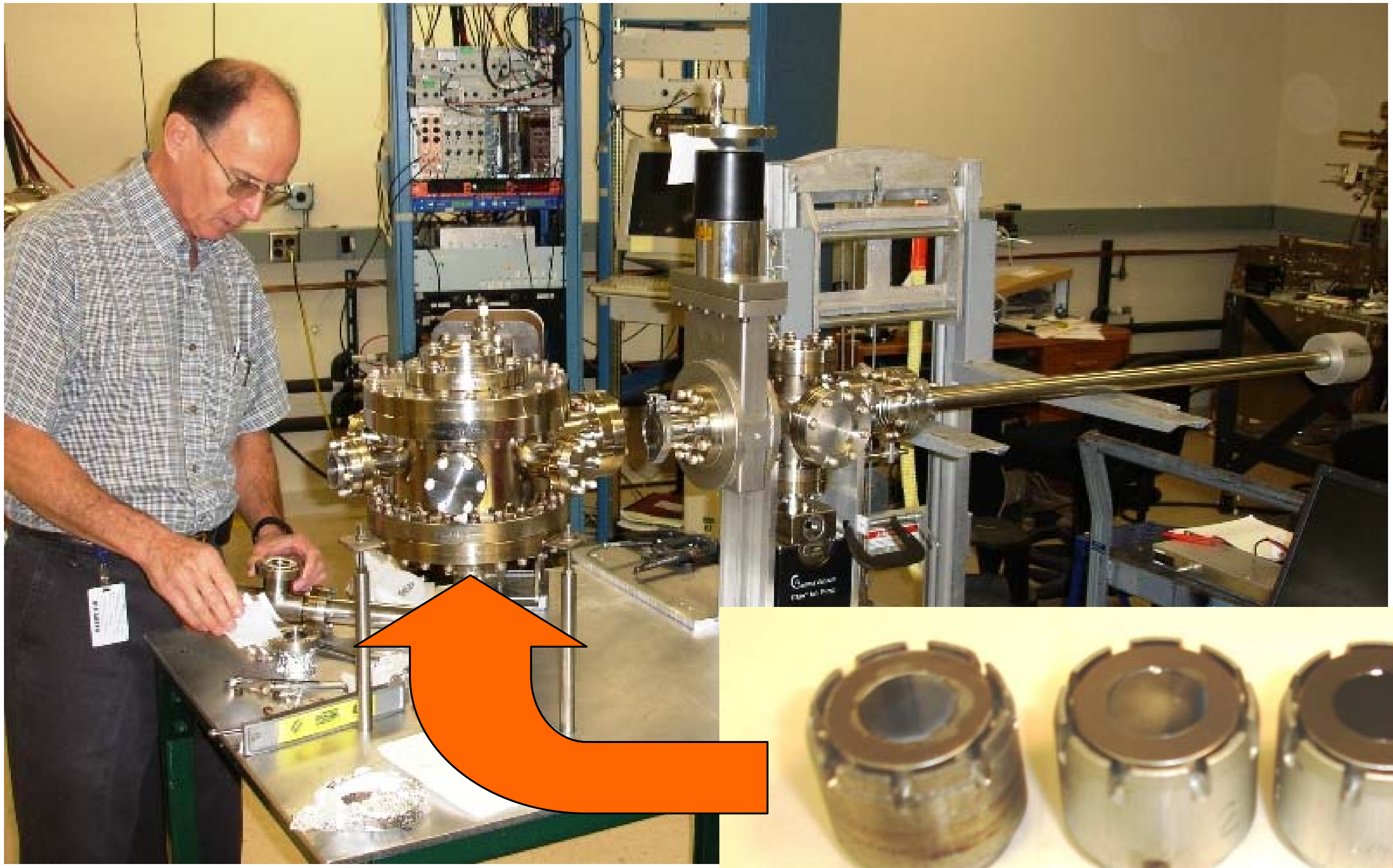
Top View



Activation Chamber
- Manipulators 150 C bake
- New & Used puck storage

Suitcase & Load Lock Chamber
- Mount wafer on puck in lab
- Holds 4 pucks (e.g., bulk, SL, SSL)
- Load Lock: 8 hour bake @ 250 C
- No H-Cleaning

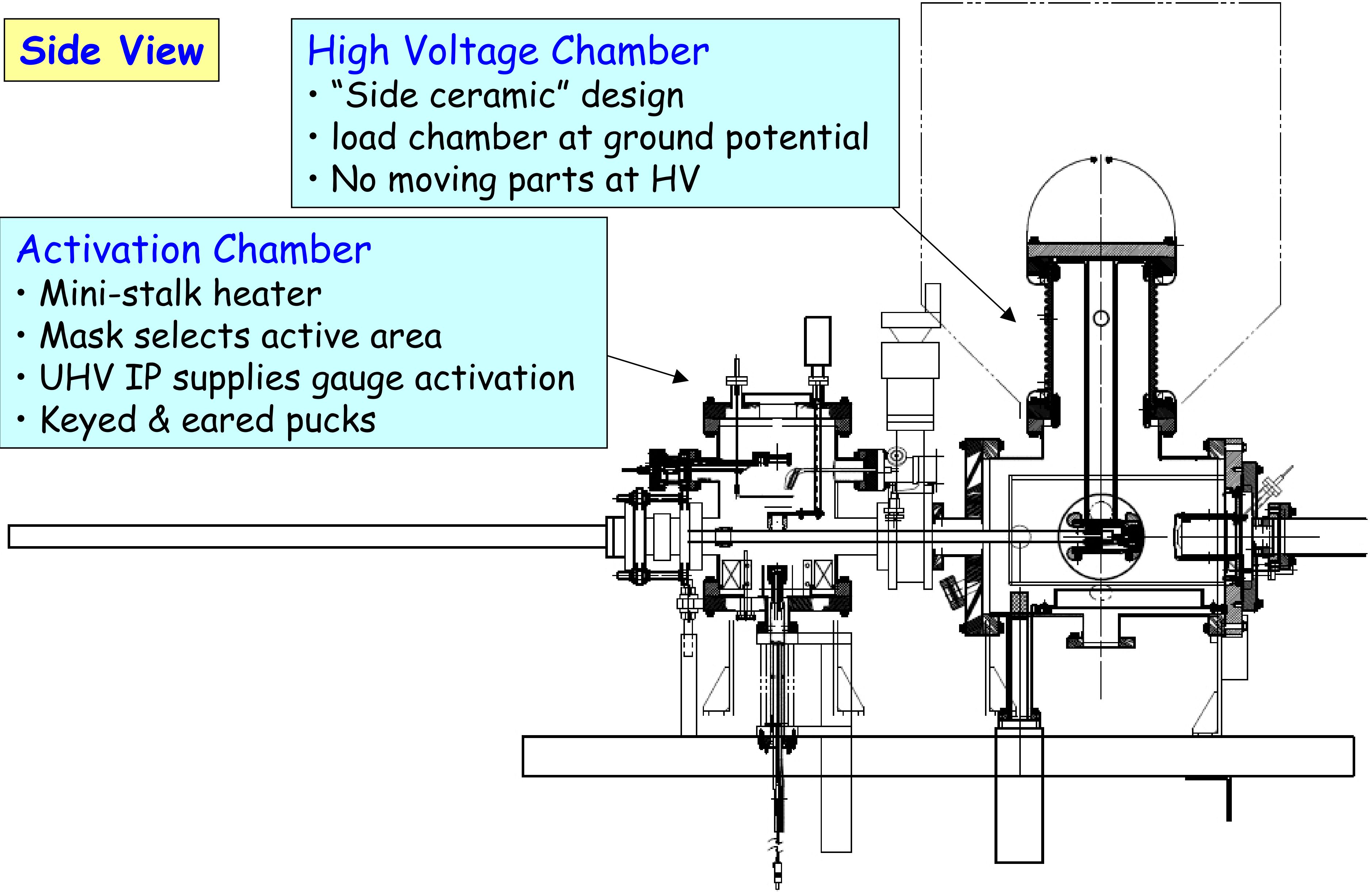
The "suitcase"



Side View

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



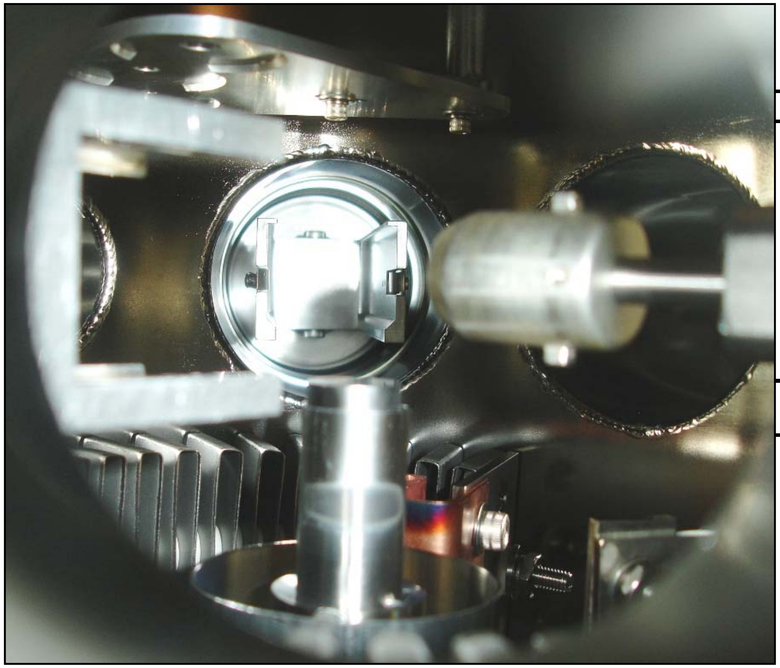
Side View

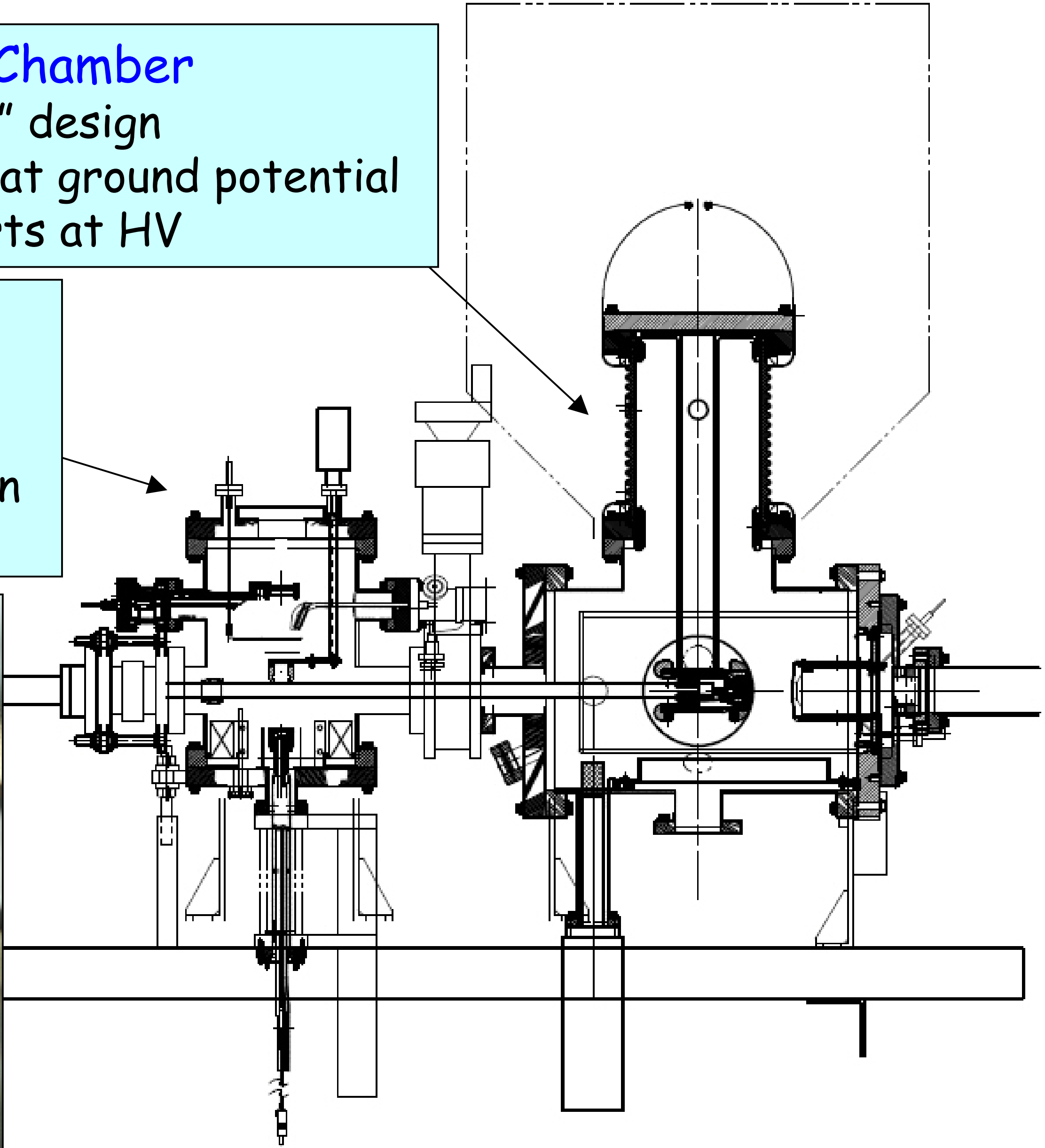
High Voltage Chamber

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

Activation Chamber

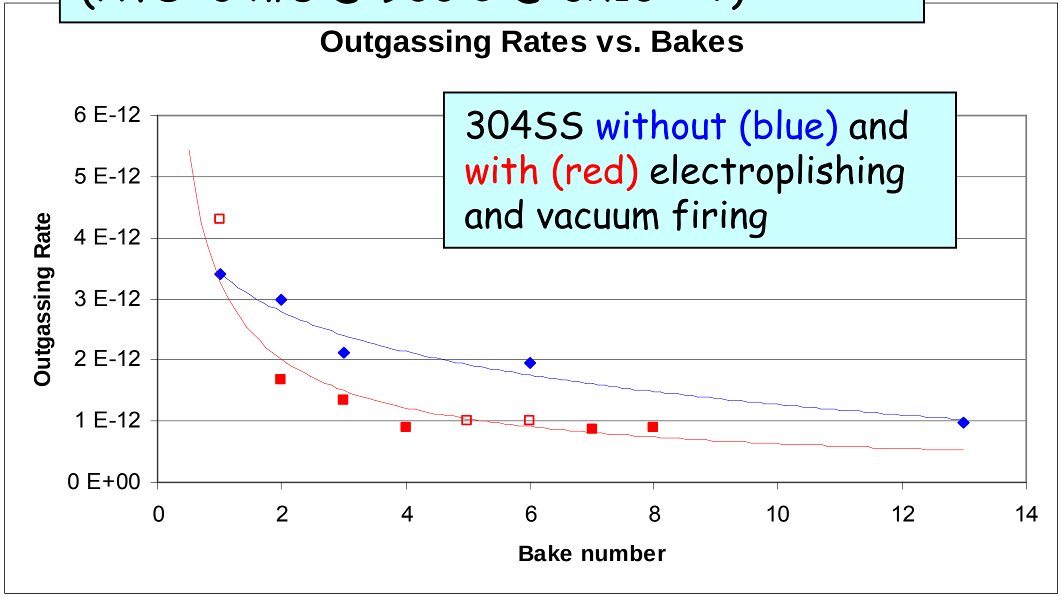
- Mini-stalk heater
- Mask selects active area
- UHV IP supplies gauge activation
- Keyed & eared pucks





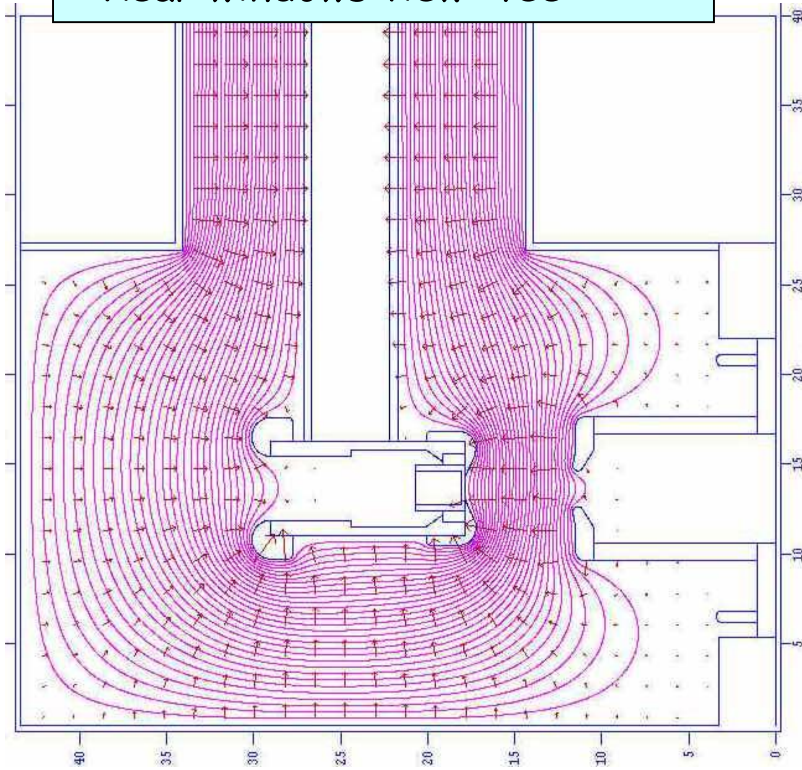
Improvements to the High Voltage Chamber

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

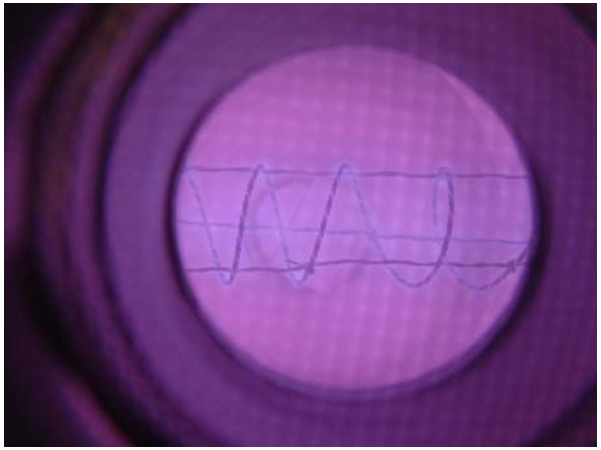


304SS without (blue) and with (red) electroplishing and vacuum firing

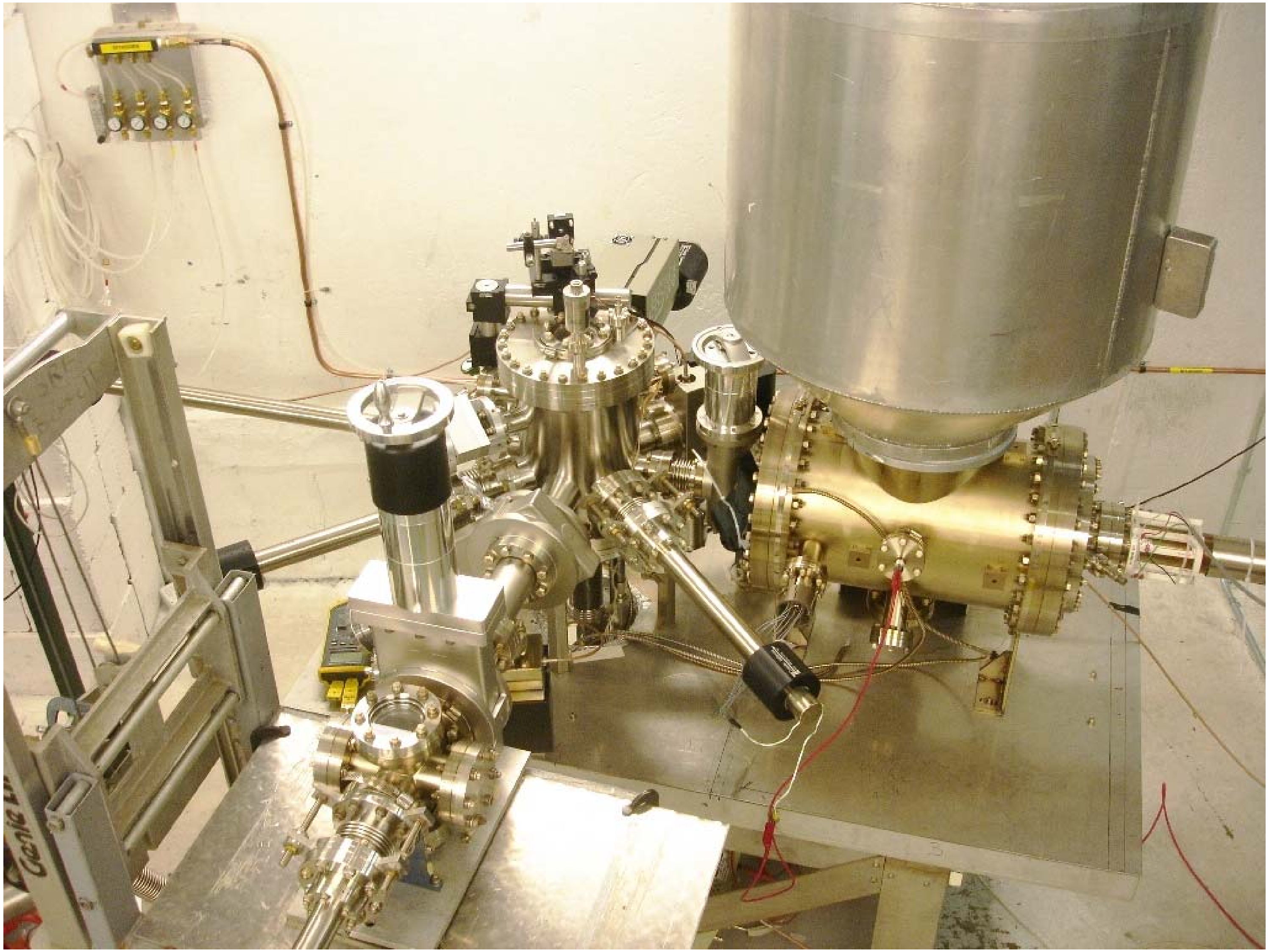
- Careful electrode alignment
- Lipped to flatten field profile
- Bias anode or support
- Rear windows view “tee”



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



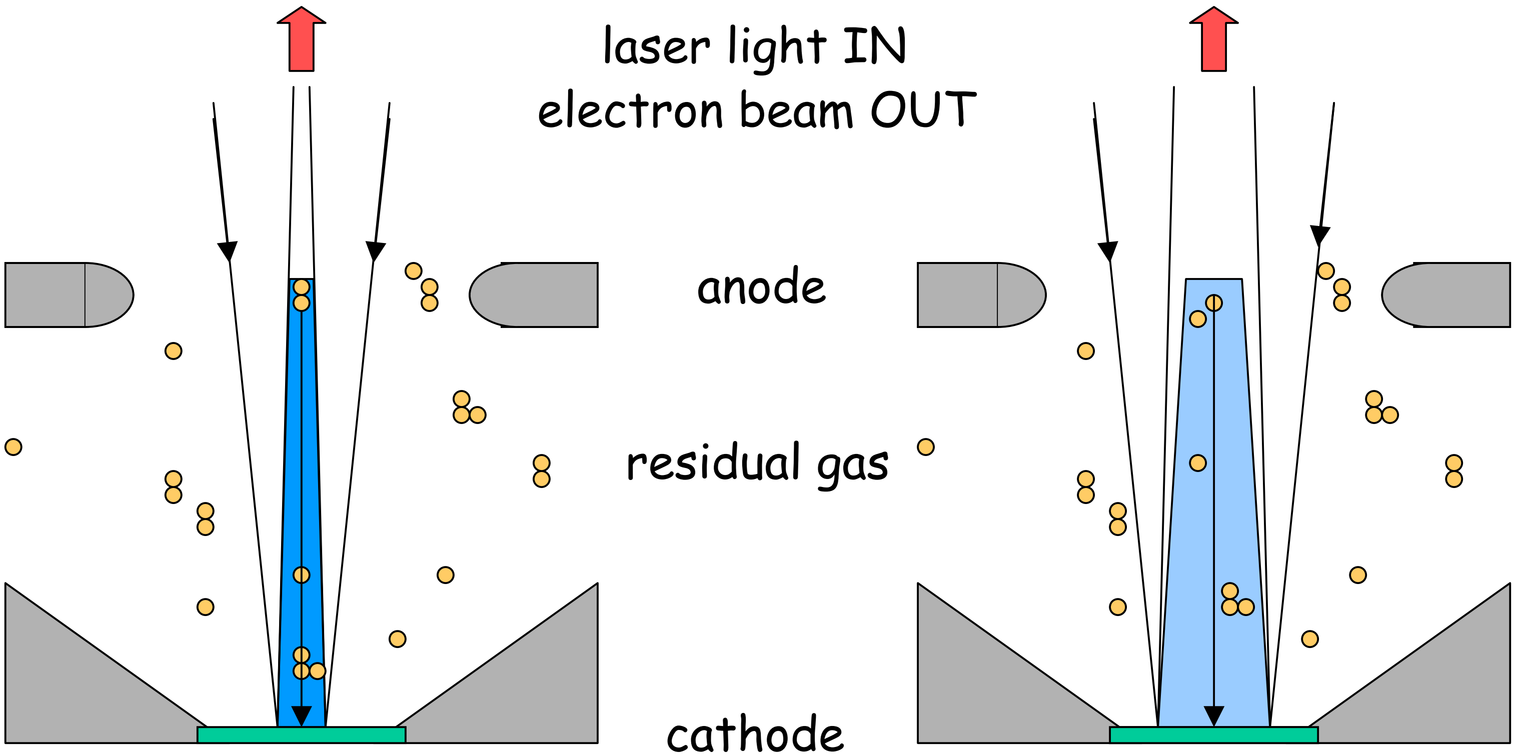
New Load Lock Gun Assembled & Running Spring '06



Benchmarking Photogun with Operational Lifetime

(Best Solution – Improve Vacuum, but this is not easy)

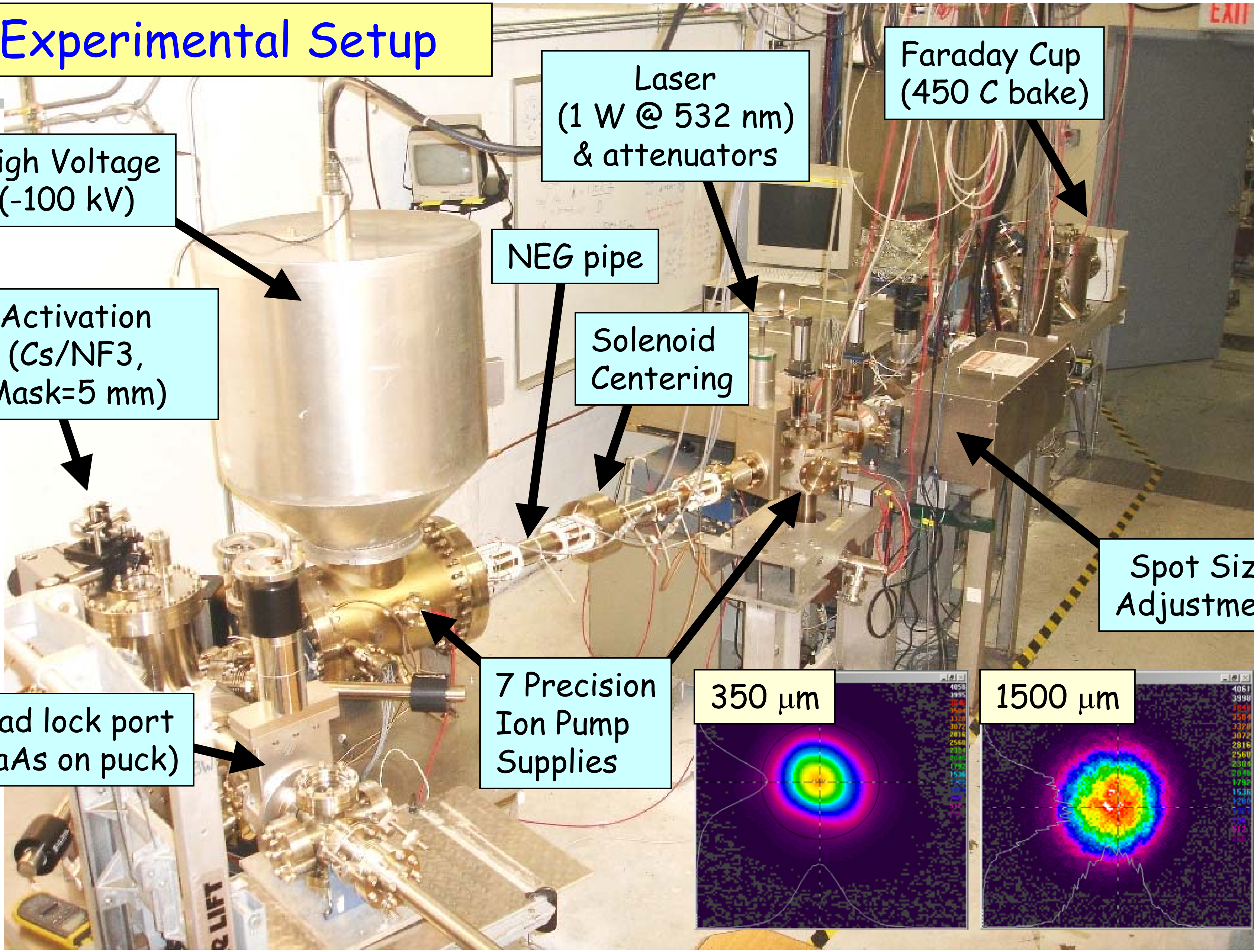
Bigger laser spot, same # electrons, same # ions



Ionized residual gas strikes photocathode

Ion damage distributed over larger area

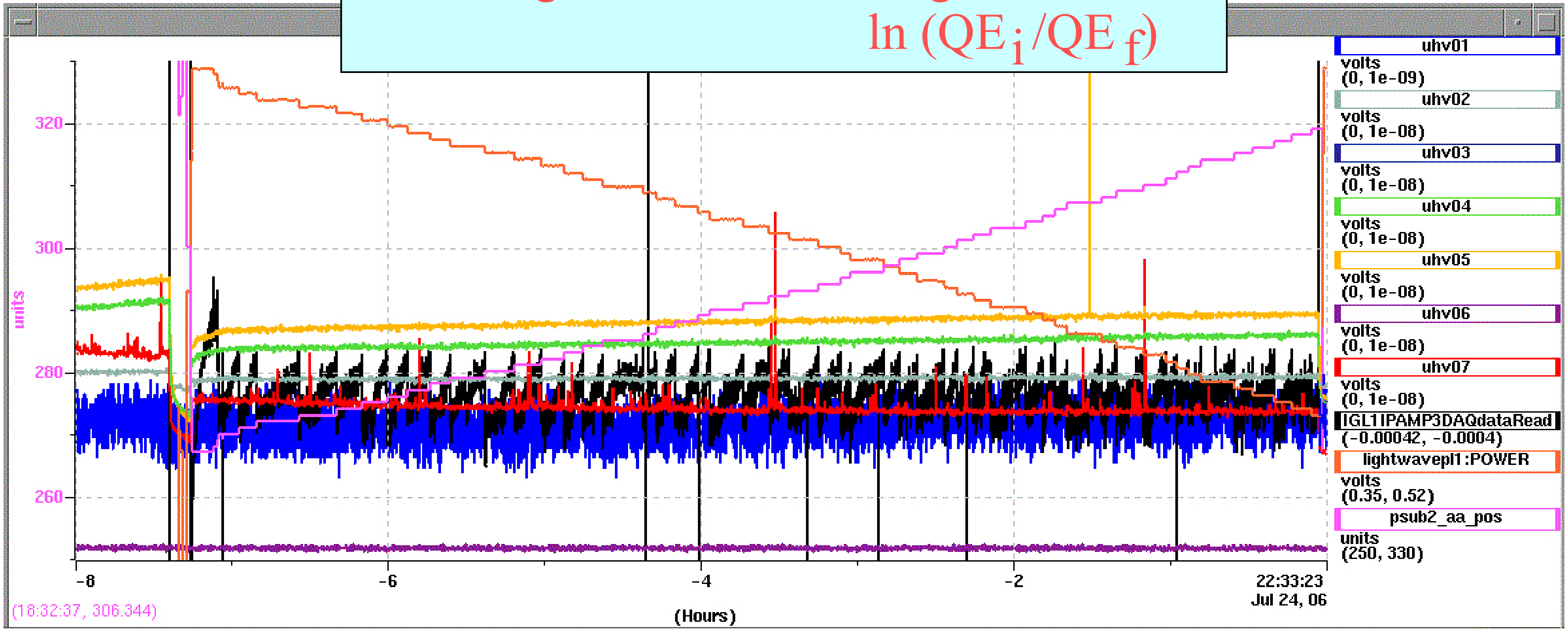
Experimental Setup



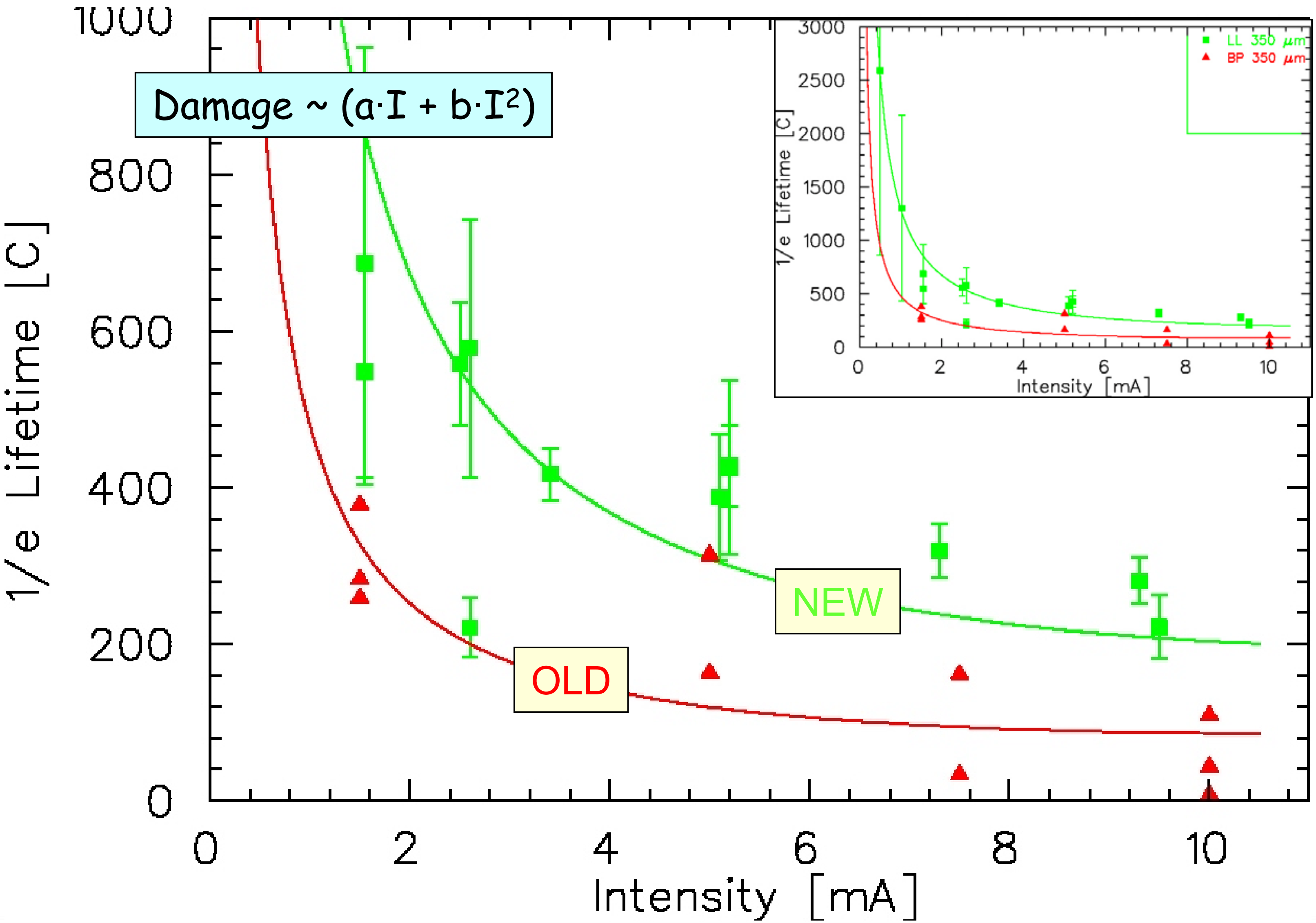
Example Run (5 mA)

- Set beam current (1-10 milliAmps) at Faraday Cup
- Run laser power (<1 Watt) PID to fix beam current
- Record ion pump current at 7 beam line locations
- Record laser power/setpoint via "pickoff" detector

$$\text{1/e Charge Lifetime} = \frac{\text{Charge Extracted}}{\ln(QE_i/QE_f)}$$

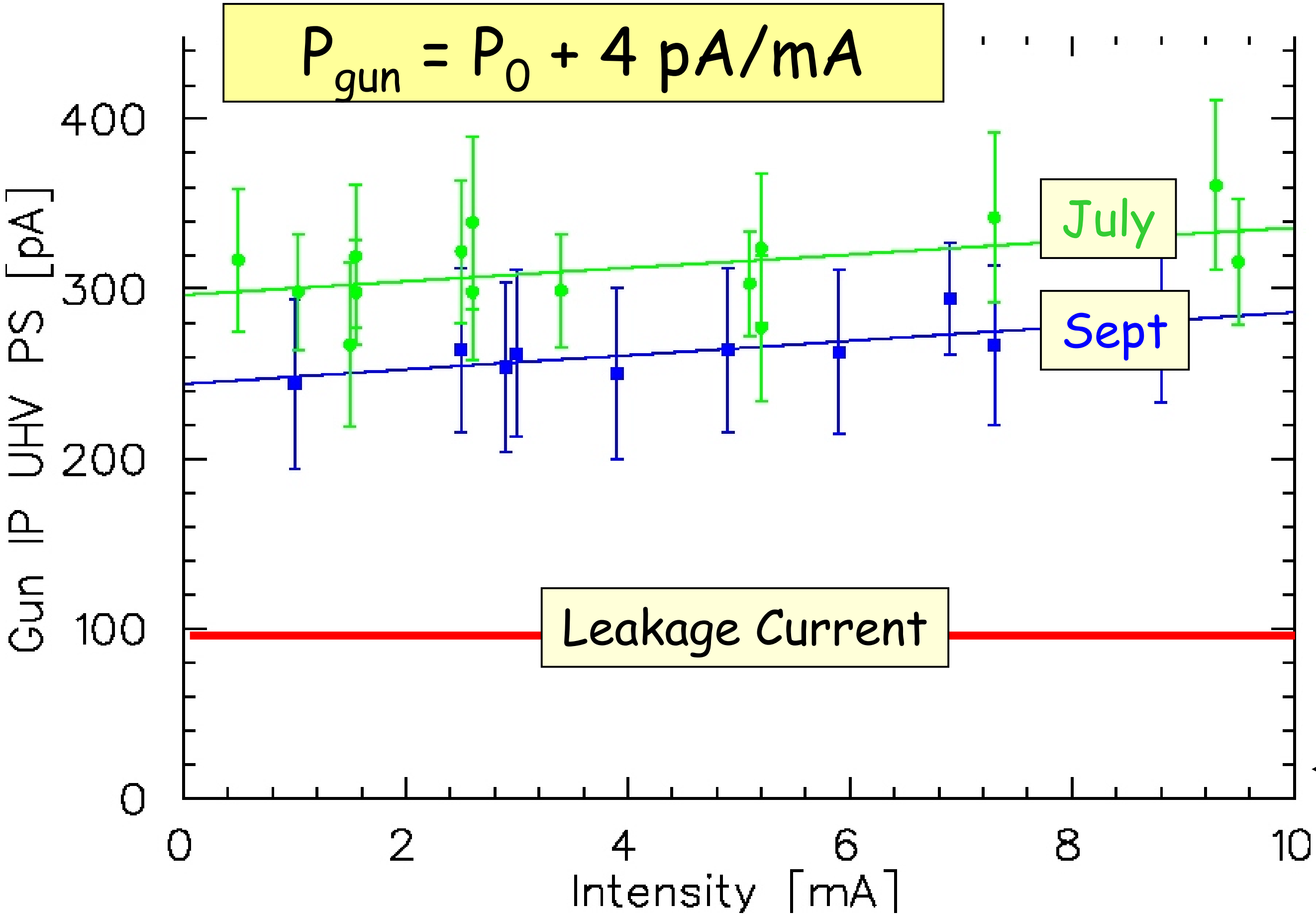


NEW vs. OLD Load Lock Design (small laser spot)



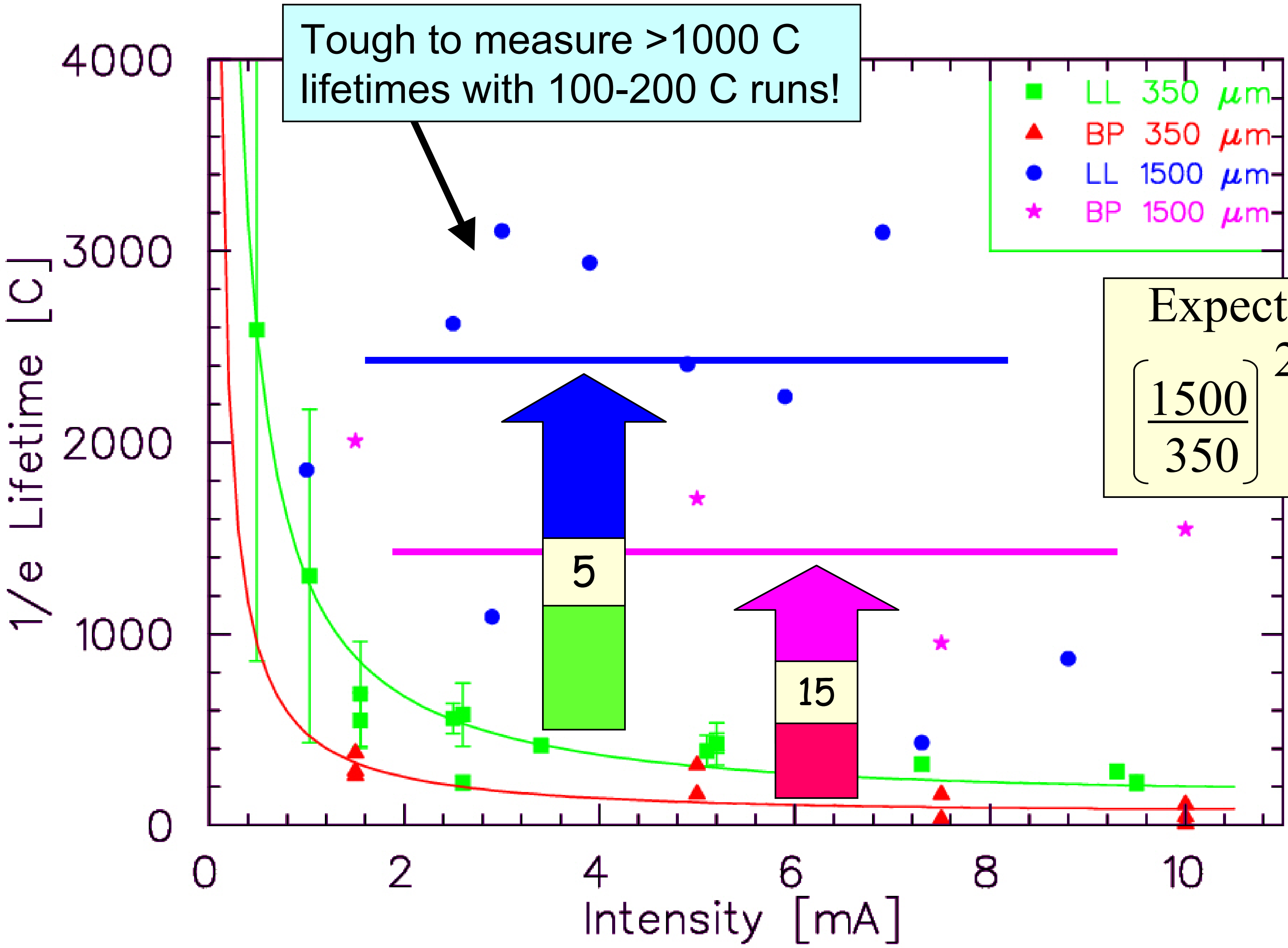
HV Chamber Pressure vs. Beam Intensity

Gun Ion Production ~ Beam Intensity x Gun Pressure ~ $(a \cdot I + b \cdot I^2)$



New UHV

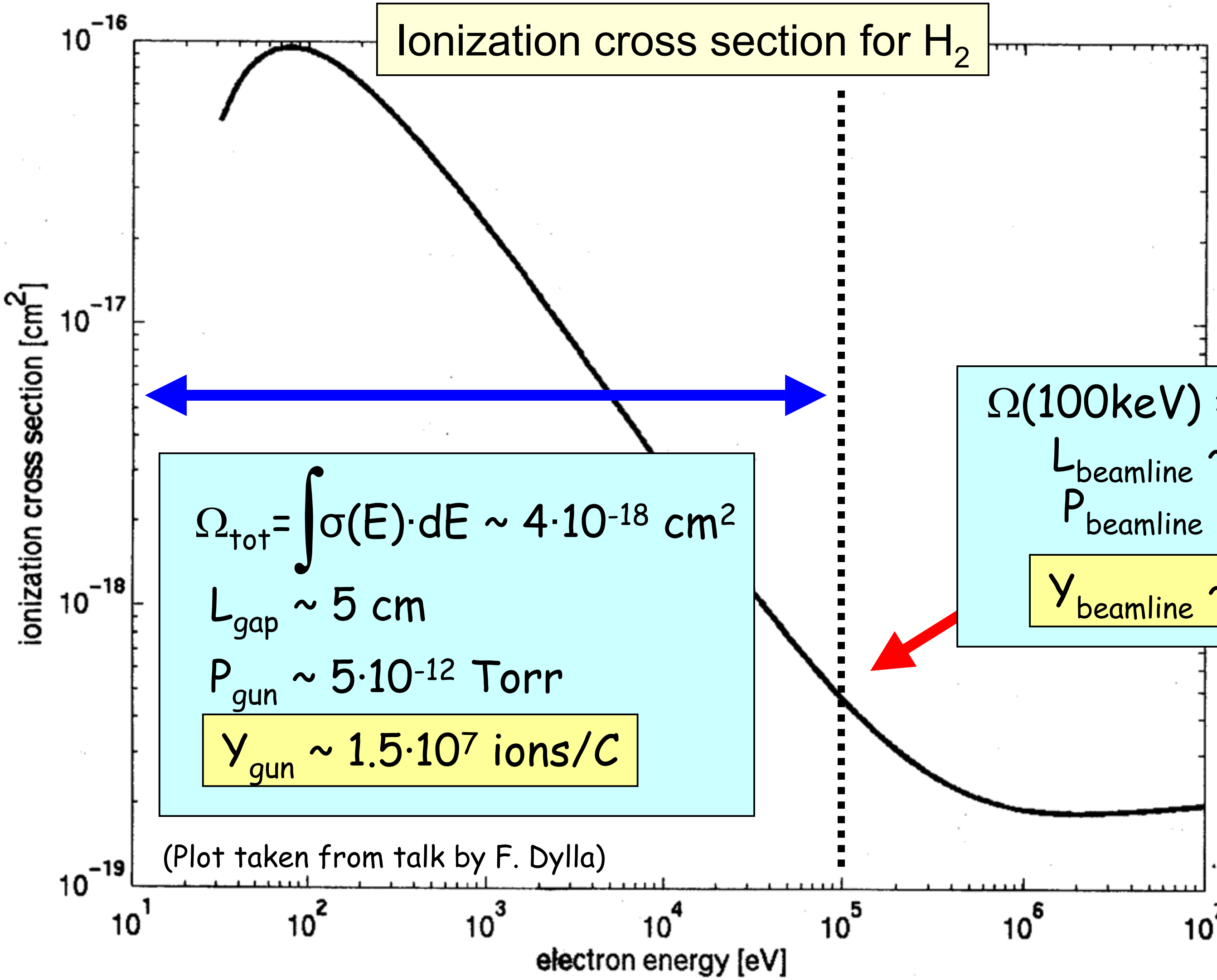
SMALL vs. LARGE Laser Spot (BP vs. LL)



Expectation:

$$\left[\frac{1500}{350}\right]^2 \approx 18$$

Is Ionized Gas from the Beamline Limiting Charge Lifetime?



$$\Omega_{tot} = \int \sigma(E) \cdot dE \sim 4 \cdot 10^{-18}\ cm^2$$

$L_{gap} \sim 5$ cm

$P_{gun} \sim 5 \cdot 10^{-12}$ Torr

$Y_{gun} \sim 1.5 \cdot 10^7$ ions/C

$\Omega(100keV) = 4 \cdot 10^{-19}\ cm^2$

$L_{beamline} \sim 100 \cdot L_{gap}$

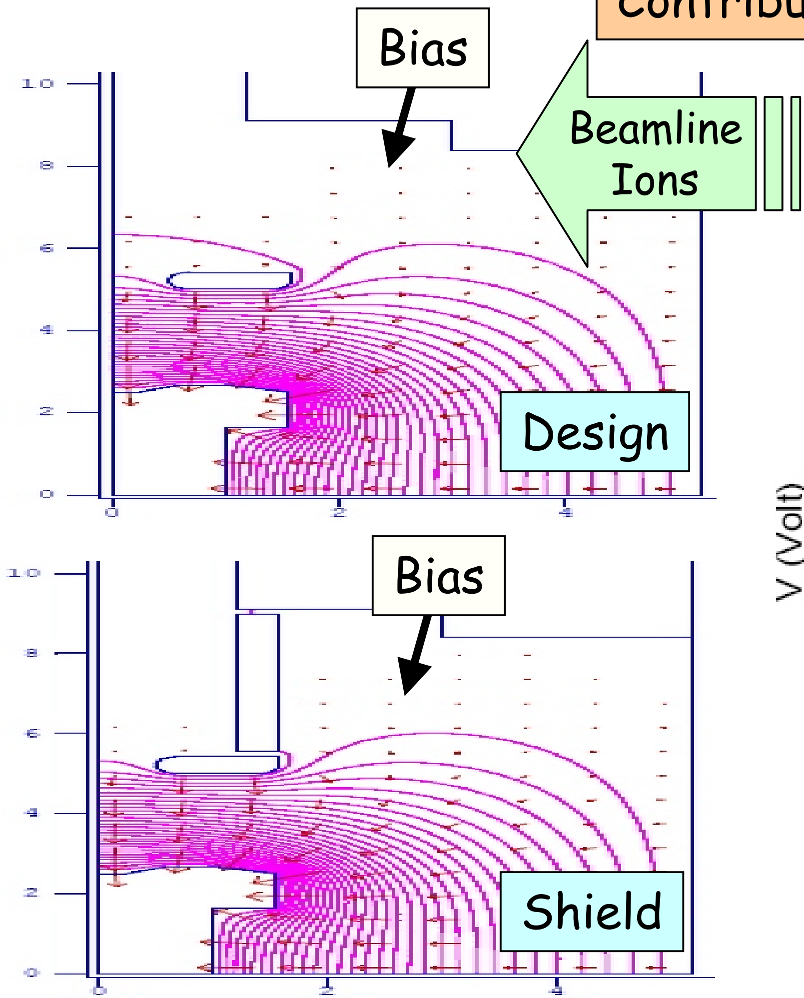
$P_{beamline} \sim 20 \cdot P_{gun}$

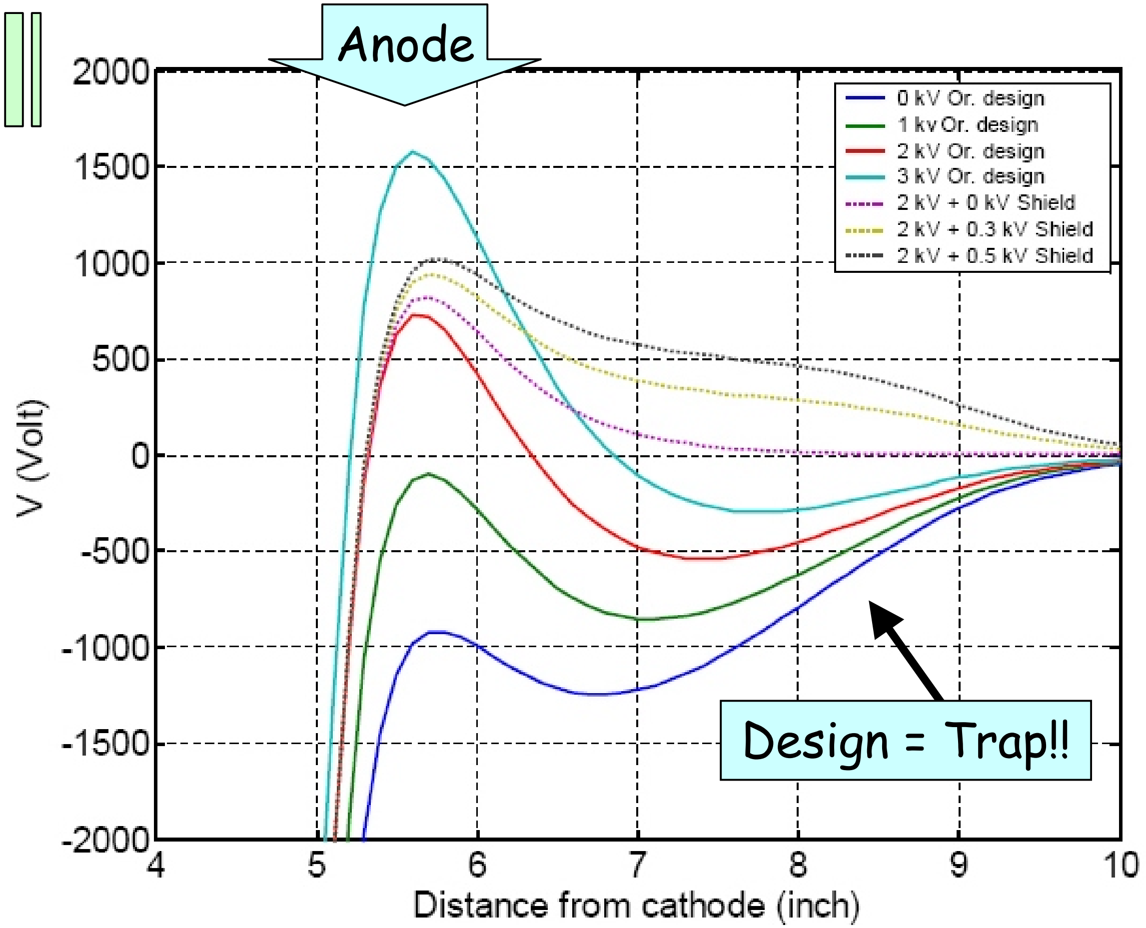
$Y_{beamline} \sim 200 \cdot Y_{gun}$

(Plot taken from talk by F. Dylla)

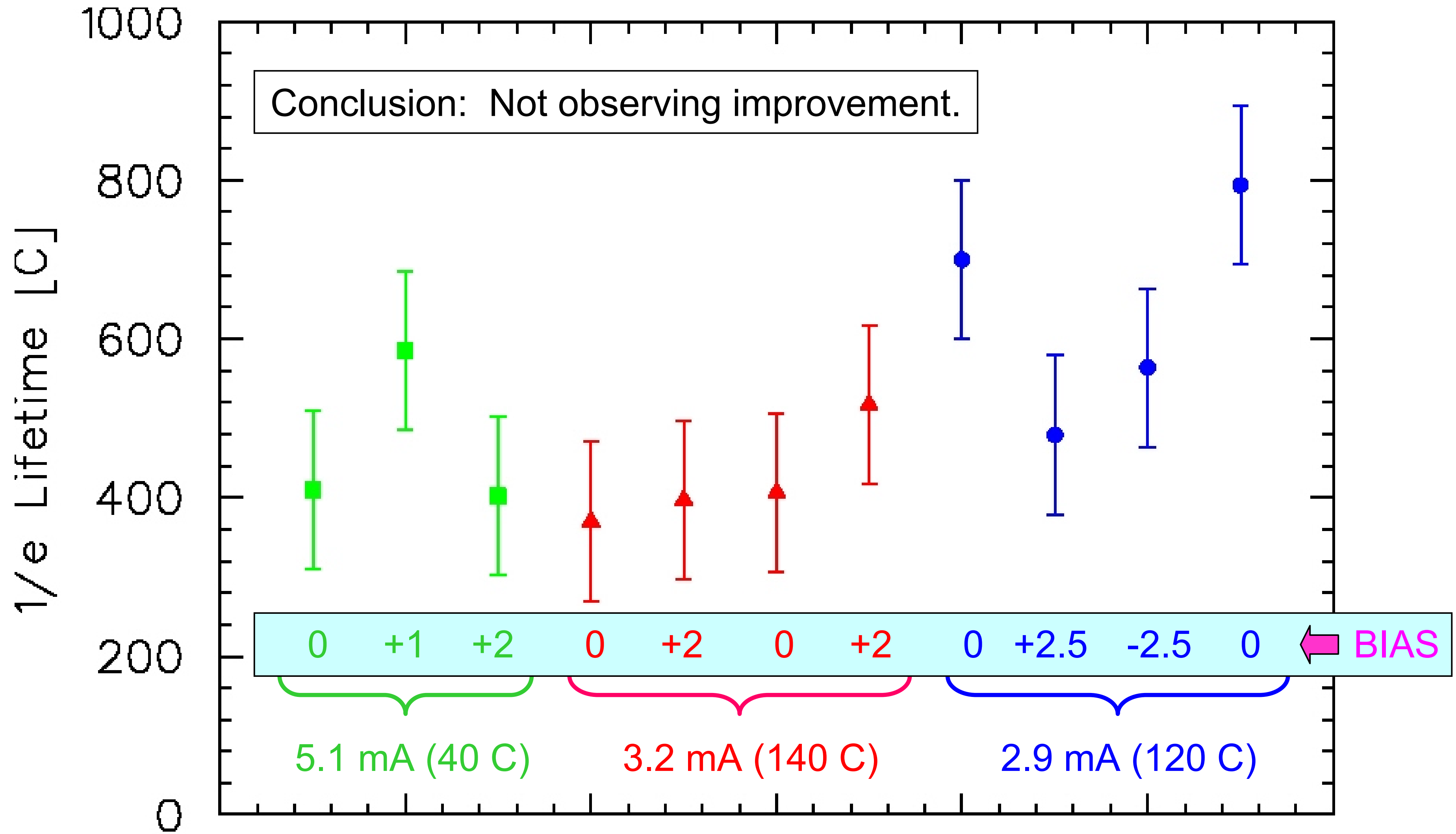
Repelling Beamline Ions with Biased Anode

Contributed by E. Pozdeyev



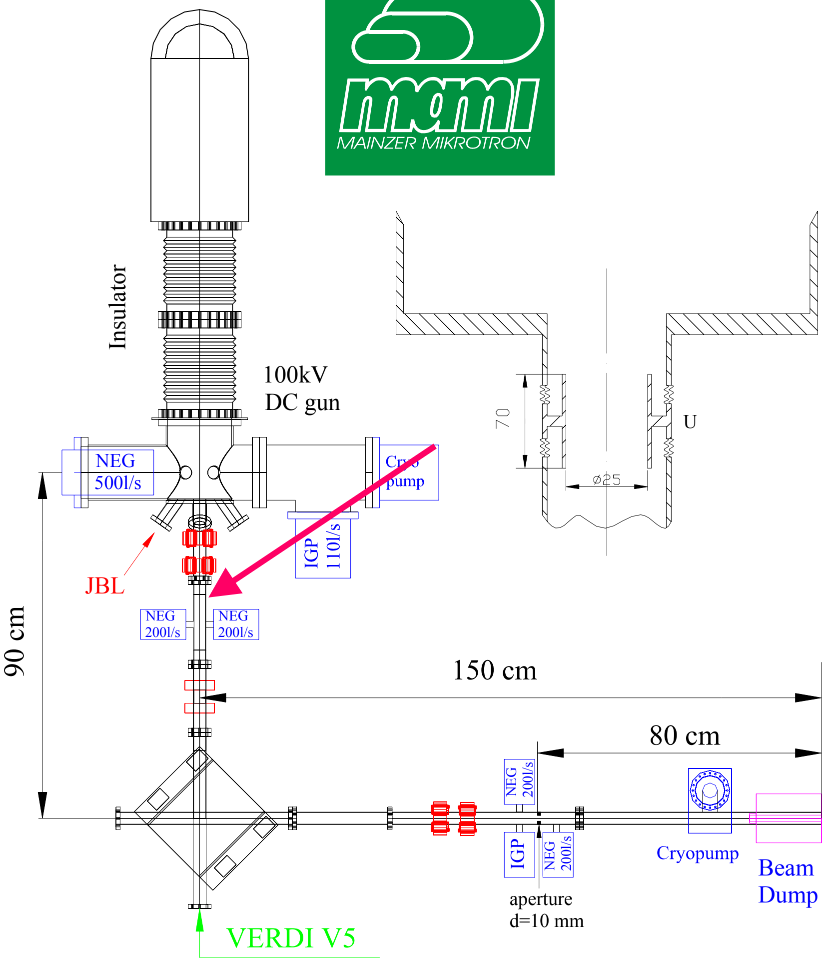


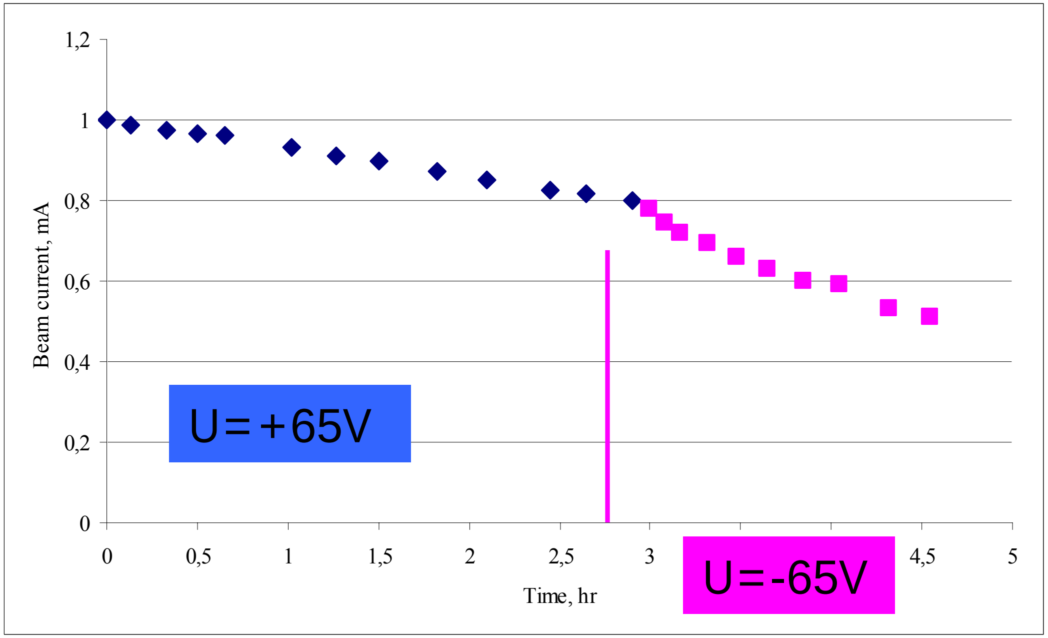
Biased Anode: Null Result ?



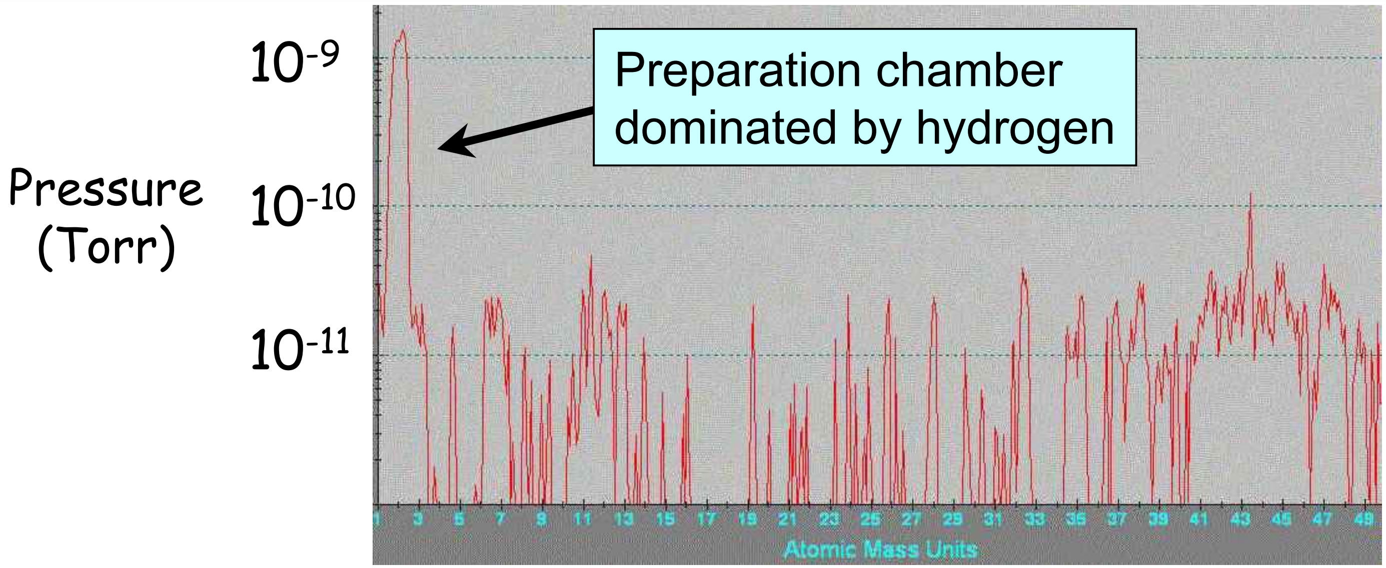
Biased Ion Repeller

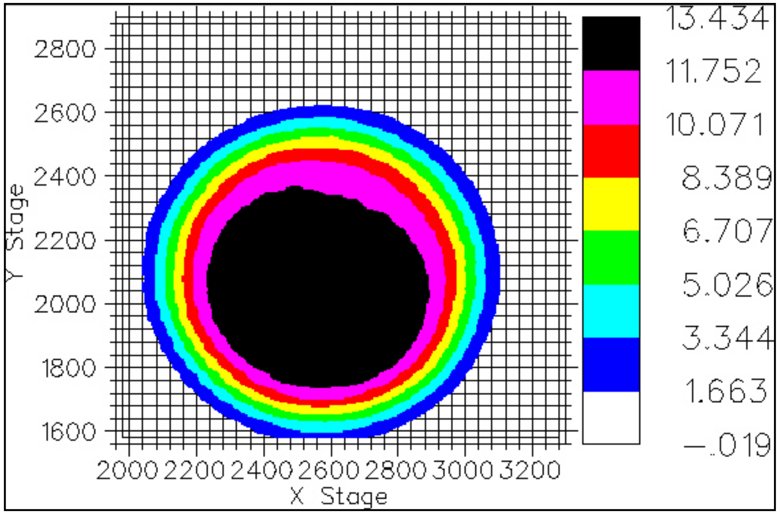
(K. Aulenbacher, University of Mainz)



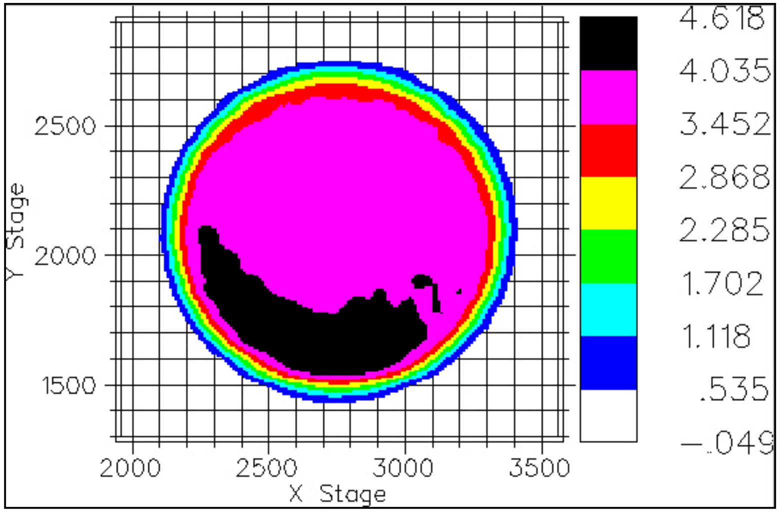


Preparation Chamber: Hydrogen Degradation of QE





30 min
~2 L

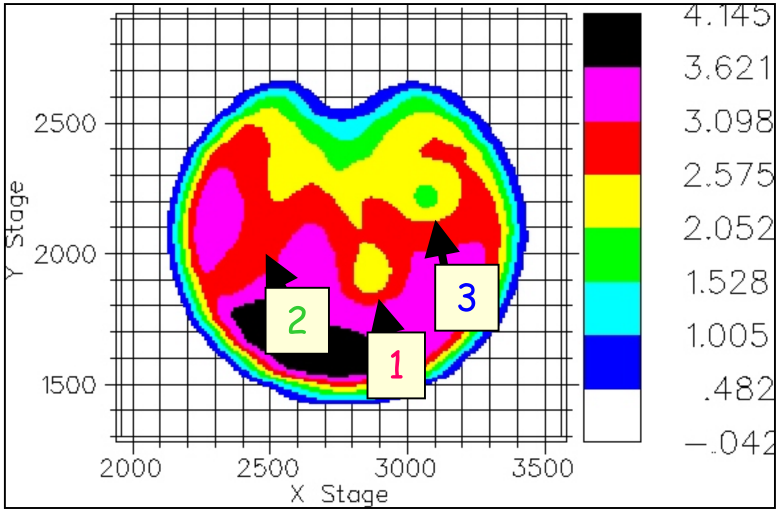


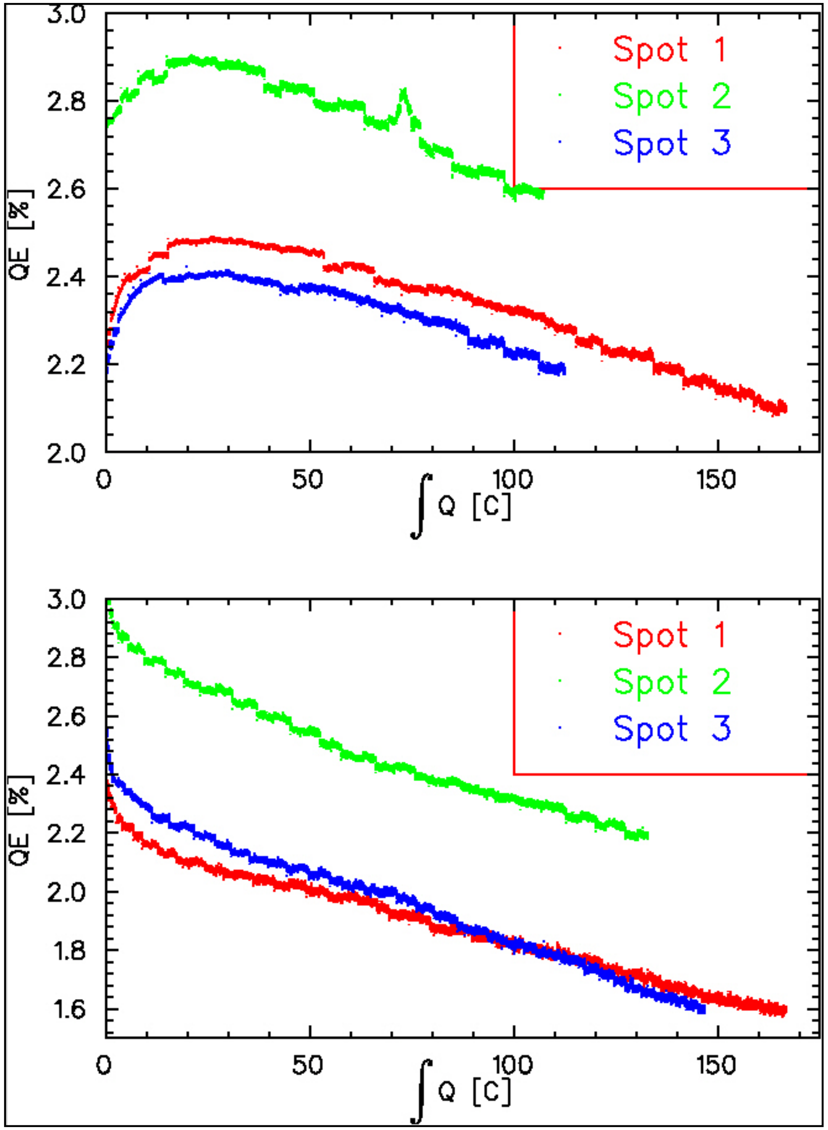
Tantalyzing Discovery: Hydrogen Barrier Enhances Lifetime

Wafer QE improves as the hydrogen barrier is removed.

All three spots ~25 C before QE starts to fall.

Once the barrier is removed QE falls as usual.



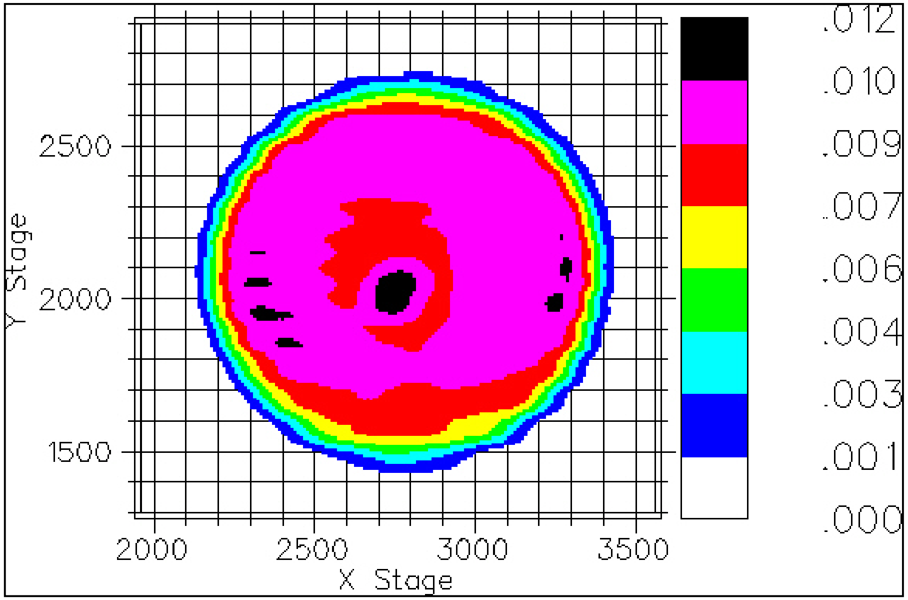


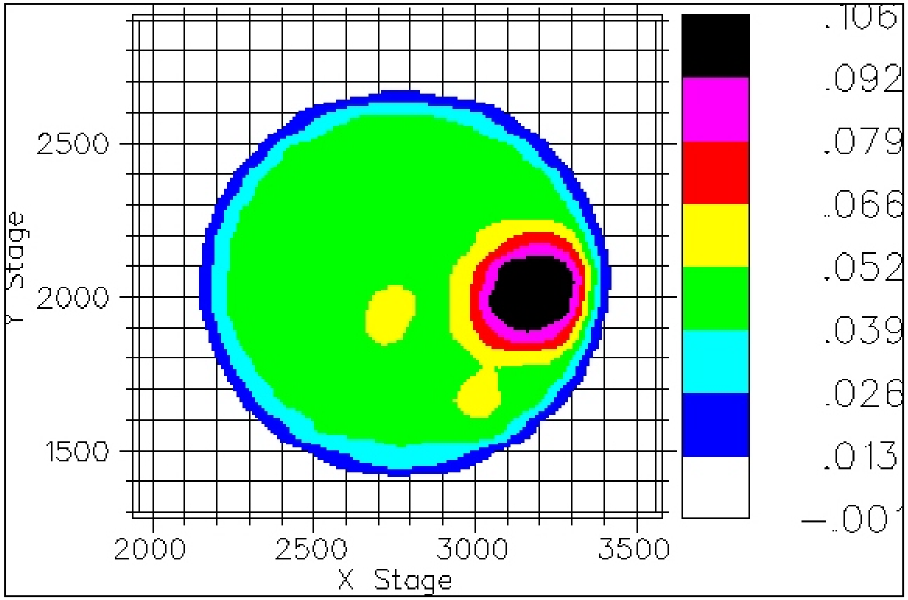
QE Largest at Beam Spot Location

2 weeks
1000x reduction
(12% to 0.012%)

$\sim 10^3$ L

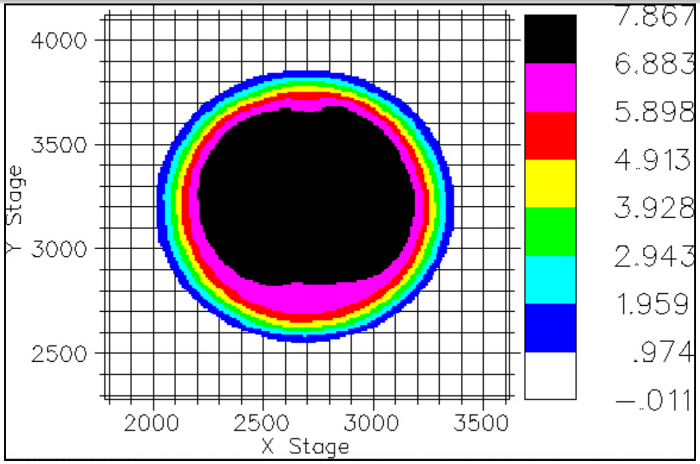
~5 Coulombs extracted
10x improvement at spot
4x improvement on surface

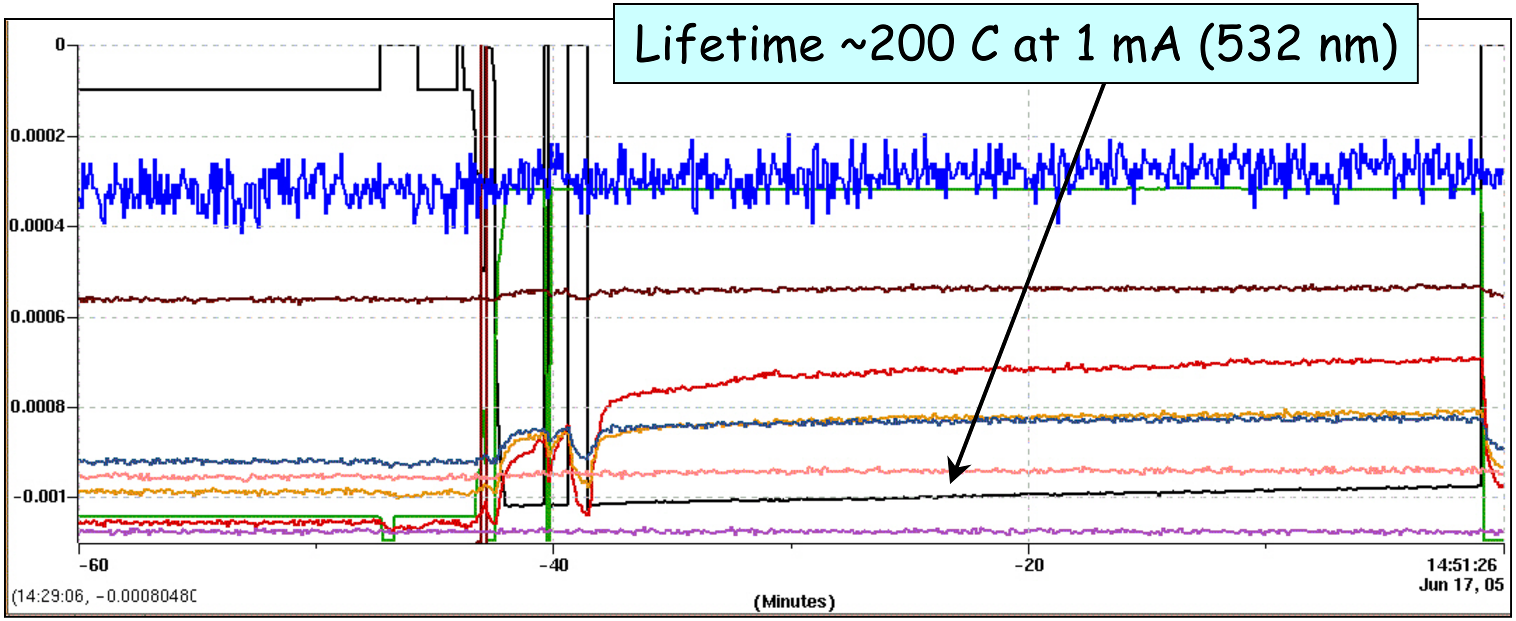




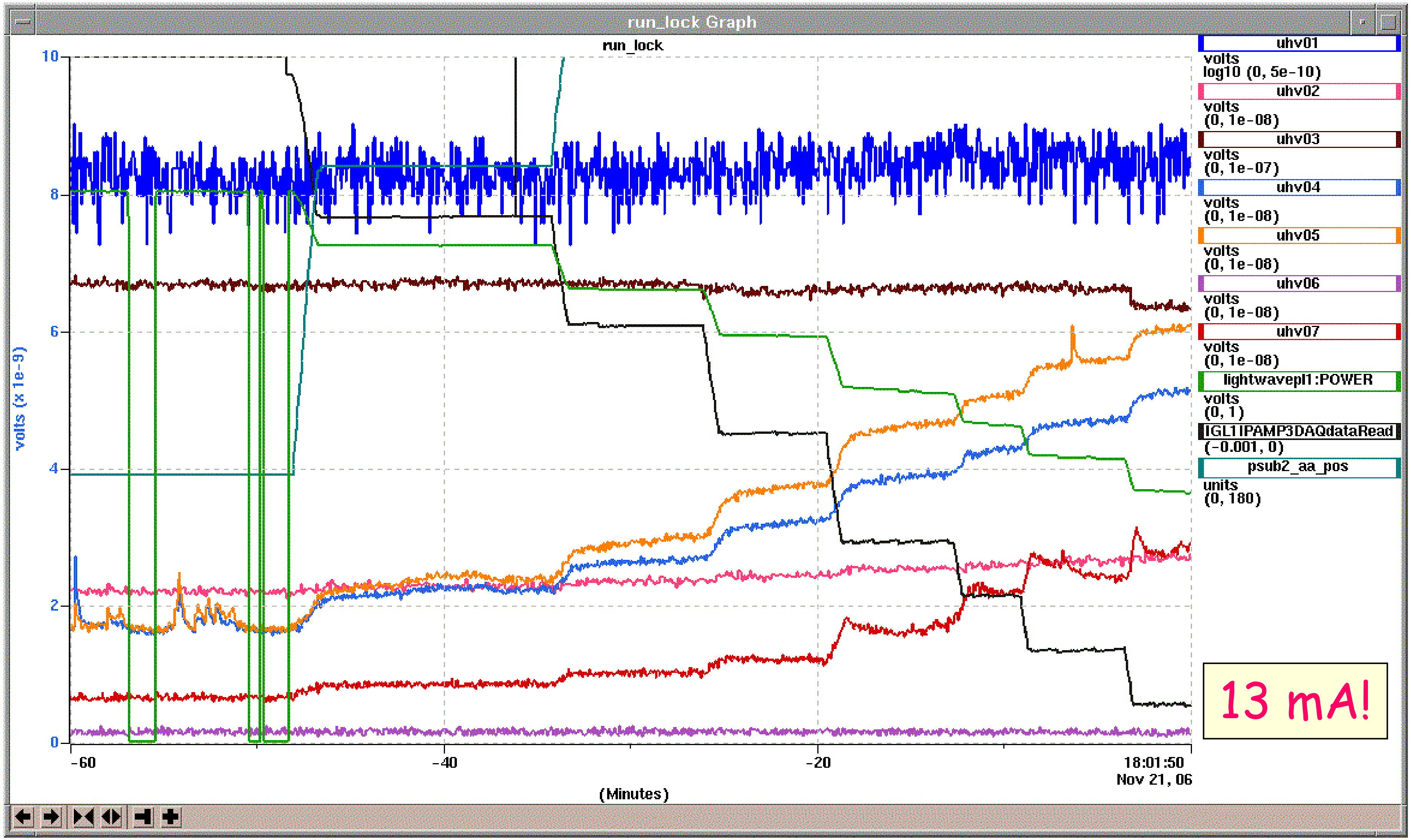
Lifetime test of strained superlattice @ 1 mA

Preliminary tests using 532 nm





We are ready to challenge our 120 kV, 16 mA PS



Summary & Outlook

Spin'06

- Exciting PES & PPS work on-going, informative meeting & fun...

- Call to "younger" PES folks to think about the future

- Useful discussions about ILC PES & JLab involvement

Summary & Outlook

NEW gun charge lifetime 2-3x better => likely vacuum, electrode improvements.

Larger laser spot improves charge lifetime, consistent with previous experiments.

Exceptionally good Charge Lifetime >1000 C at high currents >1mA
In fact, difficult to measure when using large laser spot.

Anode biasing to +/- 2.5kV yields no measurable improvement; ions created downstream of anode not a problem, at least not in test stand with good vacuum.

First demonstration of surface barrier that enhances operating lifetime, albeit at expense of initial QE. Look for other coating material that preserves QE, but does not reduce QE.

=> Photocathode lifetime measurements at >1mA using GaAs/GaAsP superlattice.

=> Install load lock in tunnel in July 2007.