High current sources for spin polarized and unpolarized electron beams

Matthew Andorf

Ivan Bazarov (PI)

HERACLES Team

Acknowledgements to:
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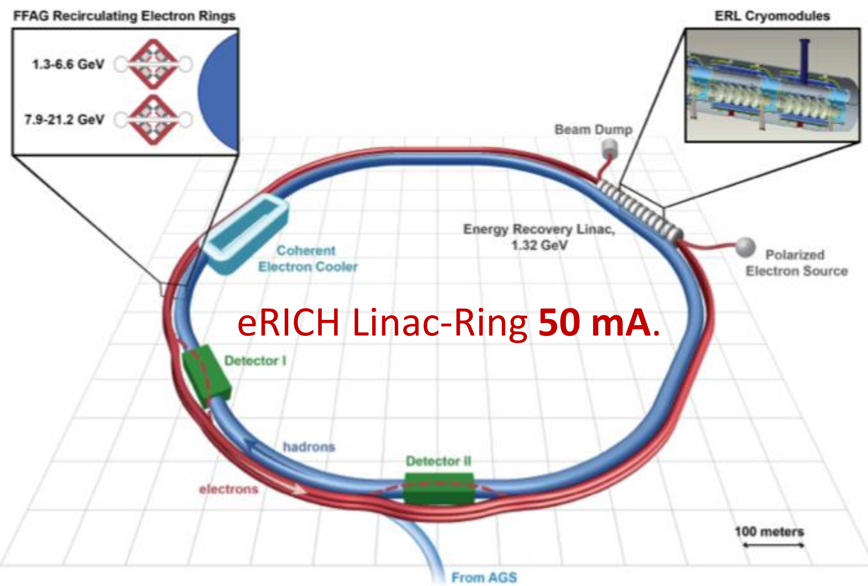
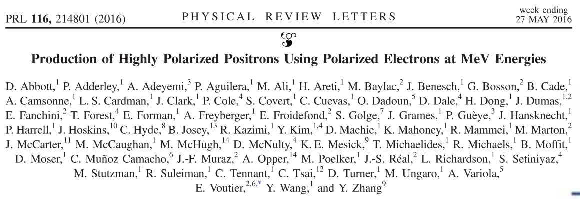
In collaboration with
- Jai Kwan Bae (Graduate student)
- Luca Cultrera (now @ BNL)
- Jared Maxson
- Ivan Bazarov
- Adam Bartnik
- Alice Galdi (now @U. of Salerno)

Outline

- Motivation
- Cornell Photoinjector Laboratory and HERACLES
- Planned High current lifetime studies:
  - Alkali Antimonide Visible vs UV illumination
  - Robust NEA activation coatings for GaAs
  - GaN photocathodes

High current and spin polarization

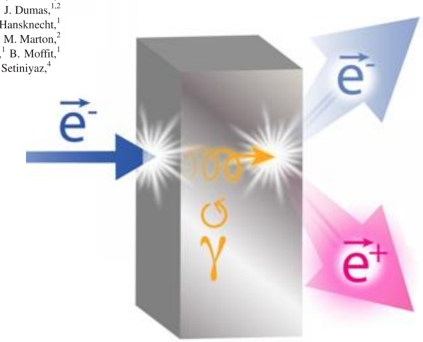


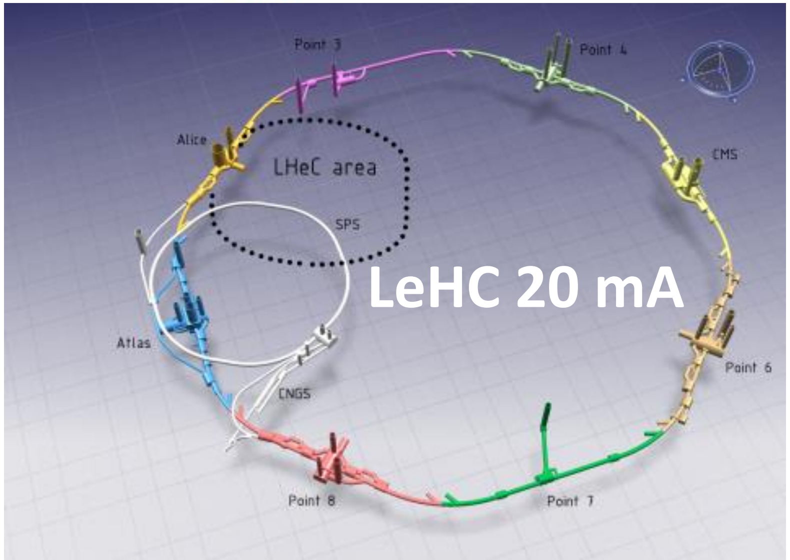

PRL **116,** 214801 (2016) PHYSICAL REVIEW LETTERS week ending 27 MAY 2016

Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies

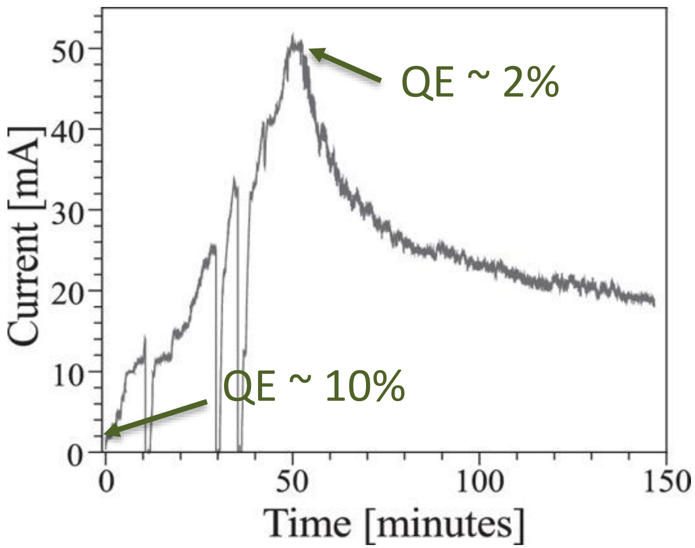
D. Abbott,[1] P. Adderley,[1] A. Adeyemi,[3] P. Aguilera,[1] M. Ali,[1] H. Areti,[1] M. Baylac,[2] J. Benesch,[1] G. Bosson,[2] B. Cade,[1] A. Camsonne,[1] L. S. Cardman,[1] J. Clark,[1] P. Cole,[4] S. Covert,[1] C. Cuevas,[1] O. Dadoun,[5] D. Dale,[4] H. Dong,[1] J. Dumas,[1,2] E. Fanchini,[2] T. Forest,[4] E. Forman,[1] A. Freyberger,[1] E. Froidefond,[2] S. Golge,[7] J. Grames,[1] P. Guèye,[3] J. Hansknecht,[1] P. Harrell,[1] J. Hoskins,[10] C. Hyde,[8] B. Josey,[13] R. Kazimi,[1] Y. Kim,[1,4] D. Machie,[1] K. Mahoney,[1] R. Mammei,[1] M. Marton,[2] J. McCarter,[11] M. McCaughan,[1] M. McHugh,[14] D. McNulty,[4] K. E. Mesick,[9] T. Michaelides,[1] R. Michaels,[1] B. Moffit,[1] D. Moser,[1] C. Muñoz Camacho,[6] J.-F. Muraz,[2] A. Opper,[14] M. Poelker,[1] J.-S. Réal,[2] L. Richardson,[1] S. Setiniyaz,[4] M. Stutzman,[1] R. Suleiman,[1] C. Tennant,[1] C. Tsai,[12] D. Turner,[1] M. Ungaro,[1] A. Variola,[5] E. Voutier,[2,6,*] Y. Wang,[1] and Y. Zhang[9]

Several mA





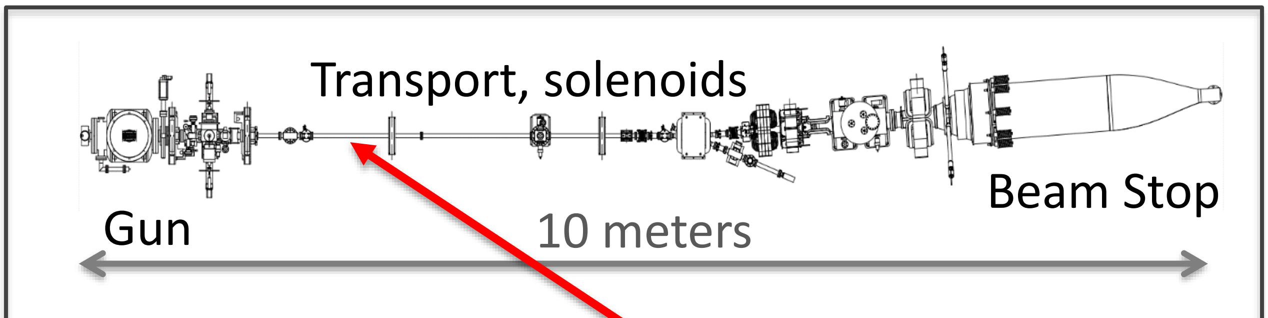
GaAs @ 532 nm (~5 Watts)
200 Coulomb

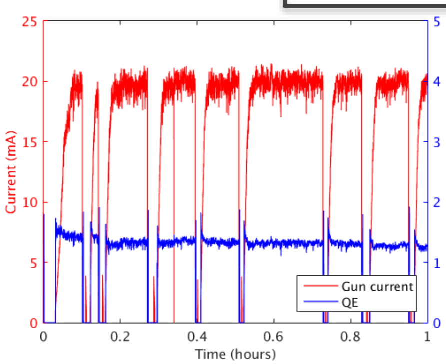


B. Dunham et al, Appl. Phys. Lett. **102**, 034105 (2013)

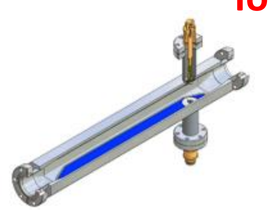
Motivation

"All three concepts rely at some point upon the high-average-current energy-recovery linac technology, *which in turn requires a high-average-current beam source*. The default option for ERLs, for both historical and technical reasons, is a photocathode electron gun using a high QE photocathode. (The gun itself is typically direct current [DC], although both normal-conducting radiofrequency [NCRF] and superconducting radiofrequency [SRF] guns have been proposed and tested.) The lifetime issues associated with high-QE photocathodes are well known and *represent significant technical challenges* in terms of replacement intervals, both from a hardware-and-technology perspective, and from an operational perspective, e.g., the beam dump recovery time."

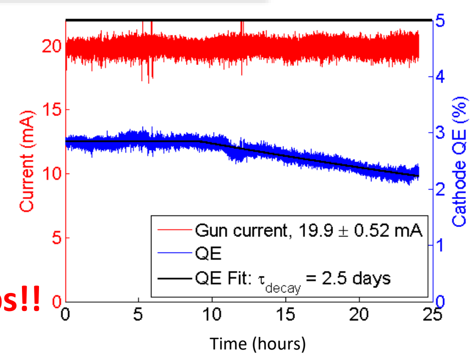




Ion Clearing Electrode

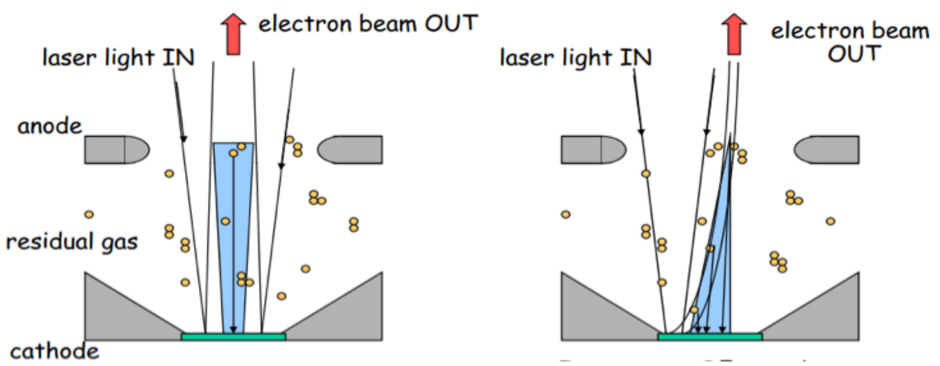


With ion clearing electrode
24 hours at 20 mA with no trips!!



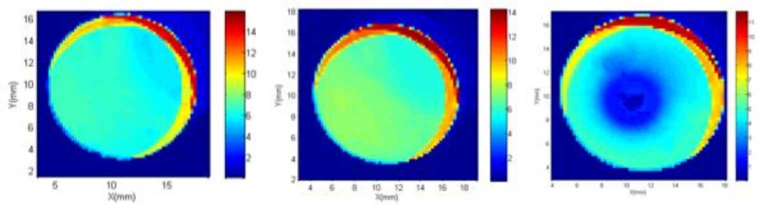
QE alone is not sufficient

- NEA is achieved and can be maintained only in **extreme vacuum**
  - XHV require massive pumping to reach **10^{-12} Torr**;
- **Ions backstreaming** is still limiting operating lifetime
  - Clearing electrodes and or biased anode;
  - Higher gun voltages;



Courtesy of J. Grames

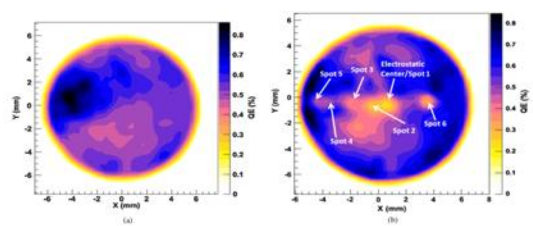
A single HV breakdown event inside the gun Can get the vacuum high enough to instantly "kill" the cathode



Fresh cathode

~10 mA
2 hours
No RF trips

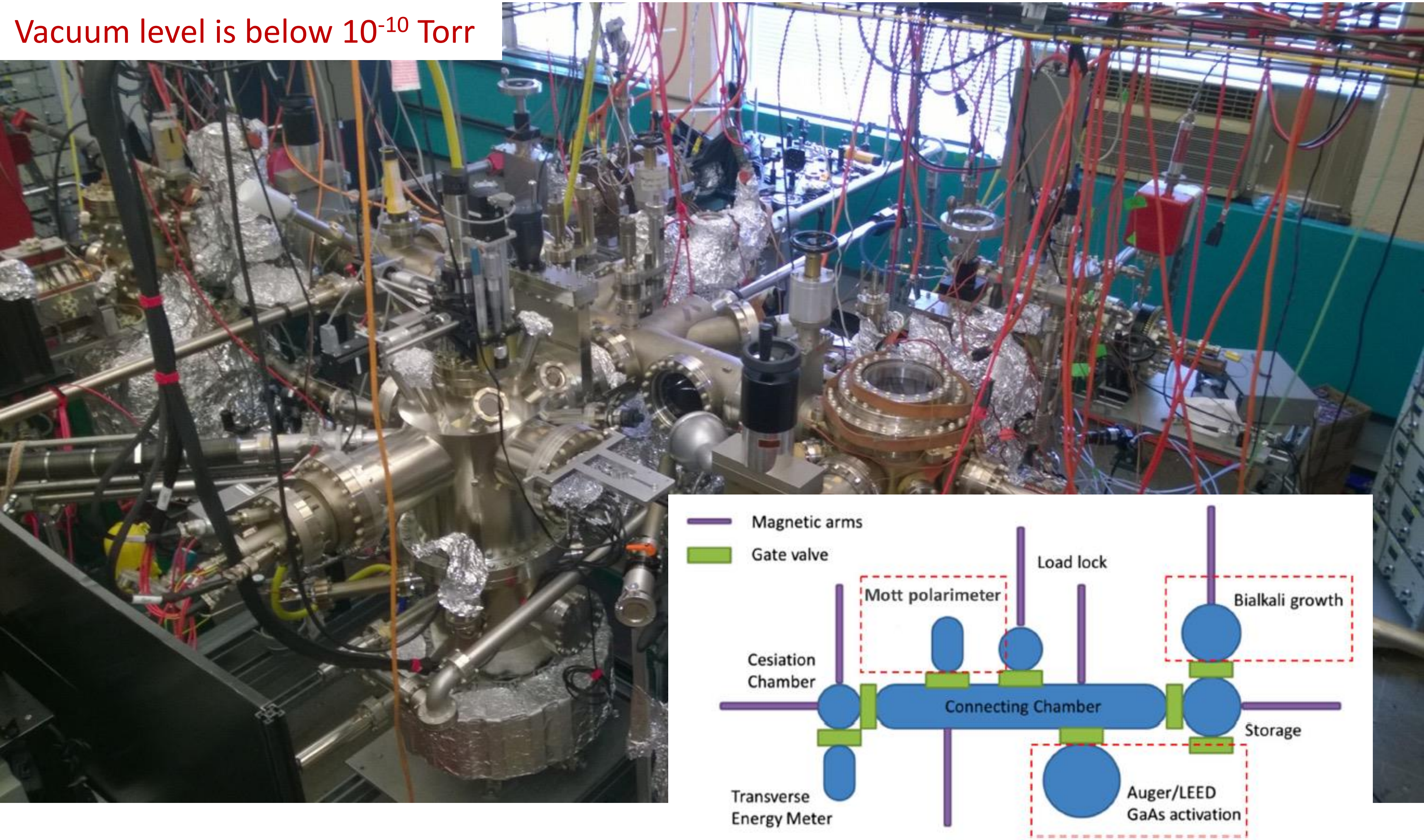
~20 mA
2 hours
many RF trips



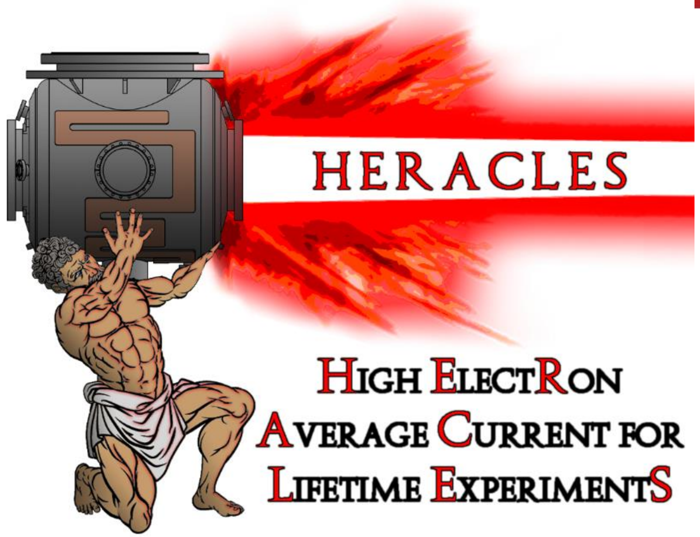
GaAs and alkali antimonides both suffer from ion backstreaming

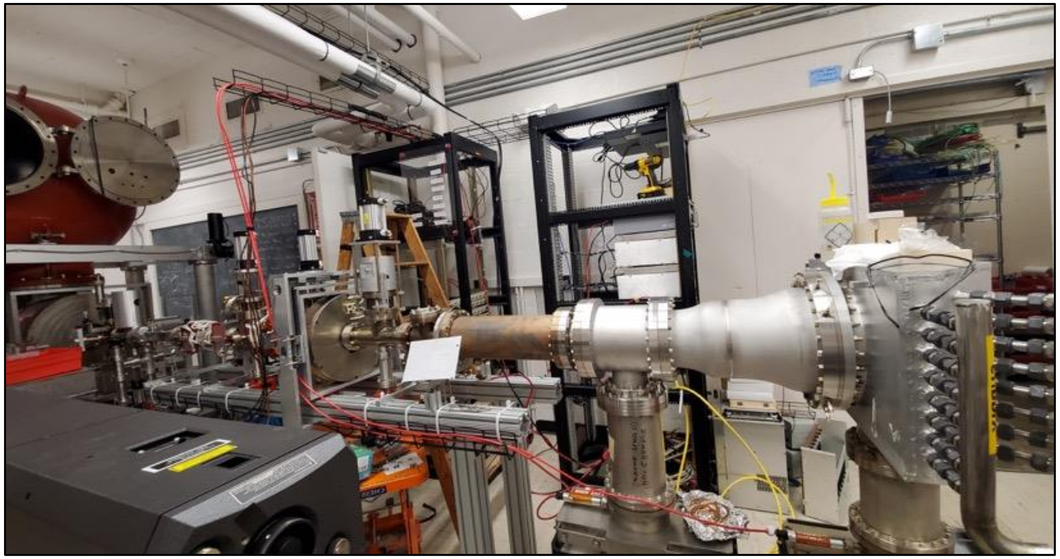
Cornell Photocathode Lab

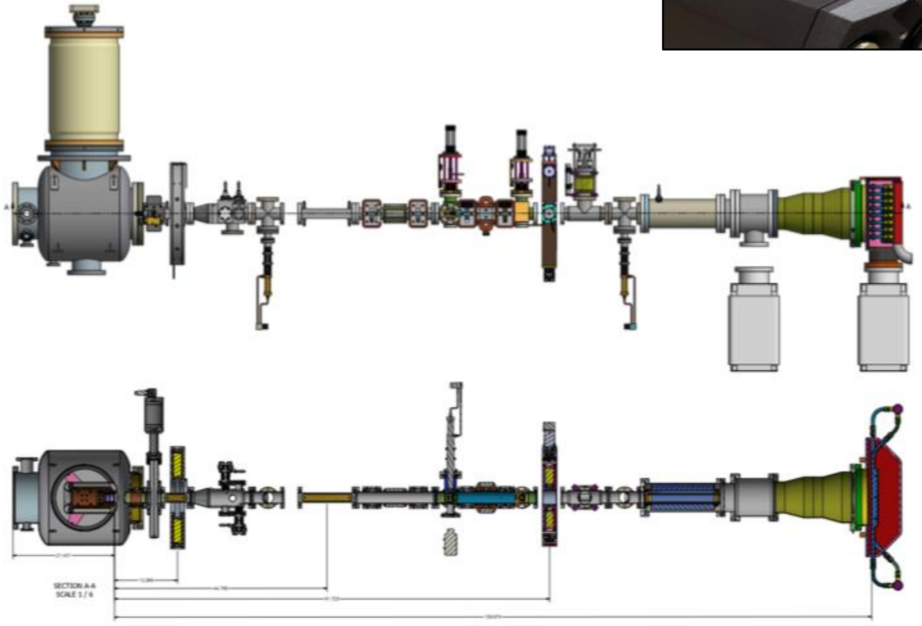
Vacuum level is below 10^{-10} Torr



The HERACLES Beamline





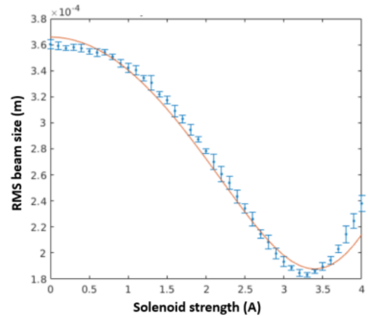


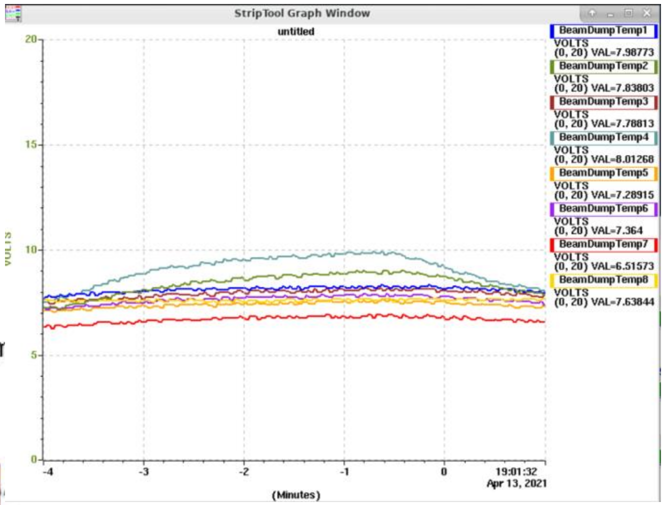
A new beamline dedicated to the study of high current beam running:

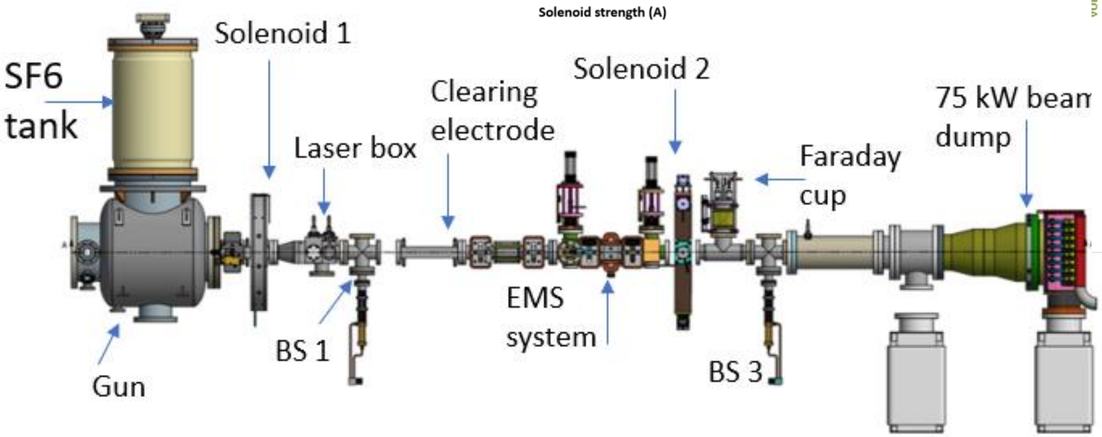
- CU-ERL gun 400kV @ 100 mA
- Ion clearing electrodes
- 75 kW beam dump
- EPICS based control system
- Attached storage system: QE mapping, Cs-O activation

Beamline and Diagnostics

Solenoid scan characterizes cathode MTE



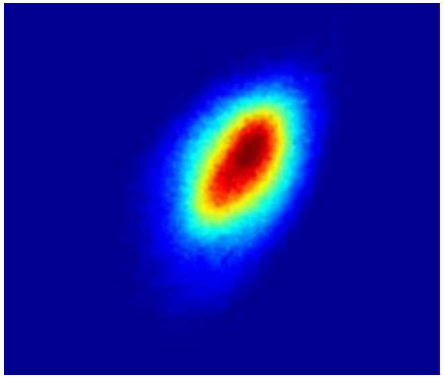




Thermal couples register beam induced temperature rise at the dump

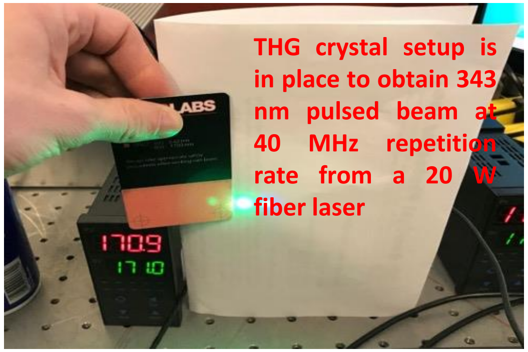
Beamline

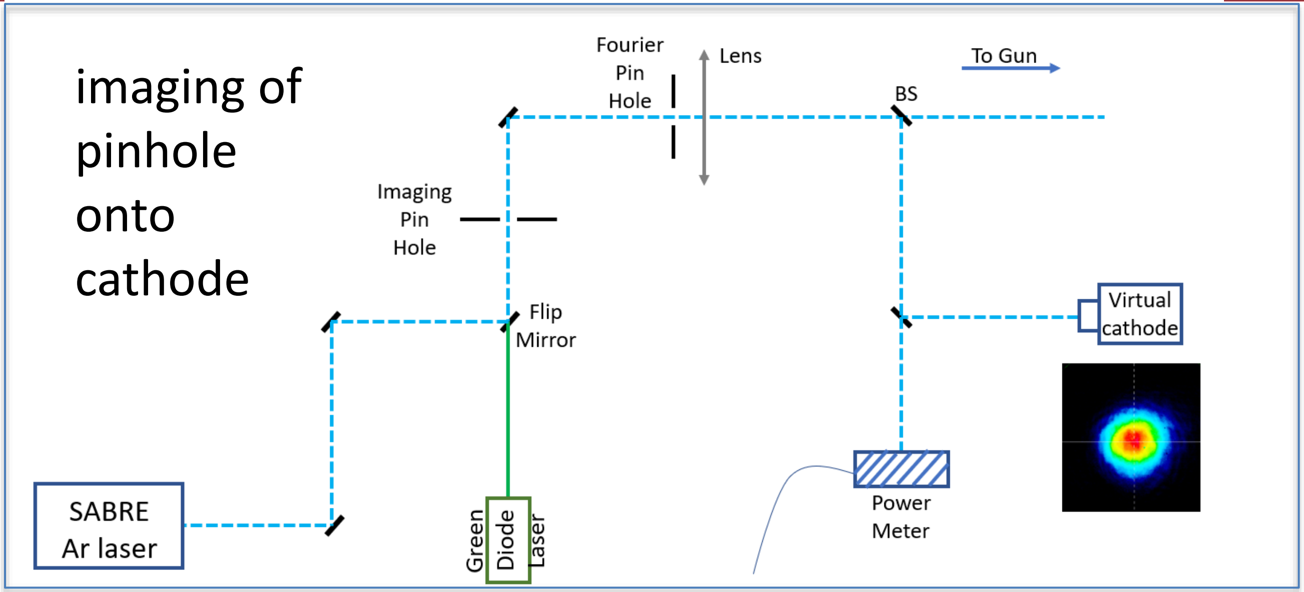
- **2 Solenoids, 3 corrector pairs (hor/vert)**
- **2 clearing electrodes**
- **3 screens, 1 quad detector**
- **1 Faraday cup**
- **EMS system not implemented**



3 Beam screens ensure clean beam transport from cathode to dump

Laser setup



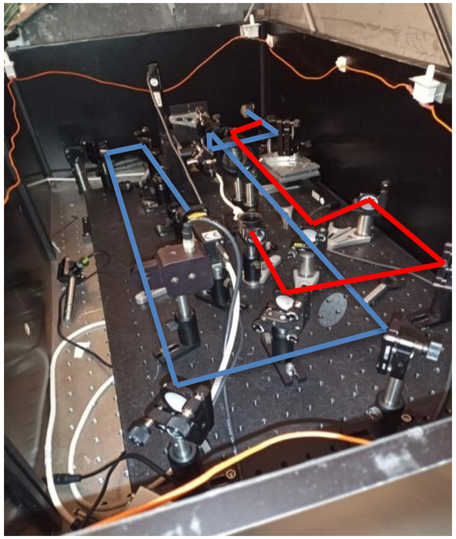


The Ar ion laser has been refurbished and now can operated with tunable wavelength in the visible and UV.

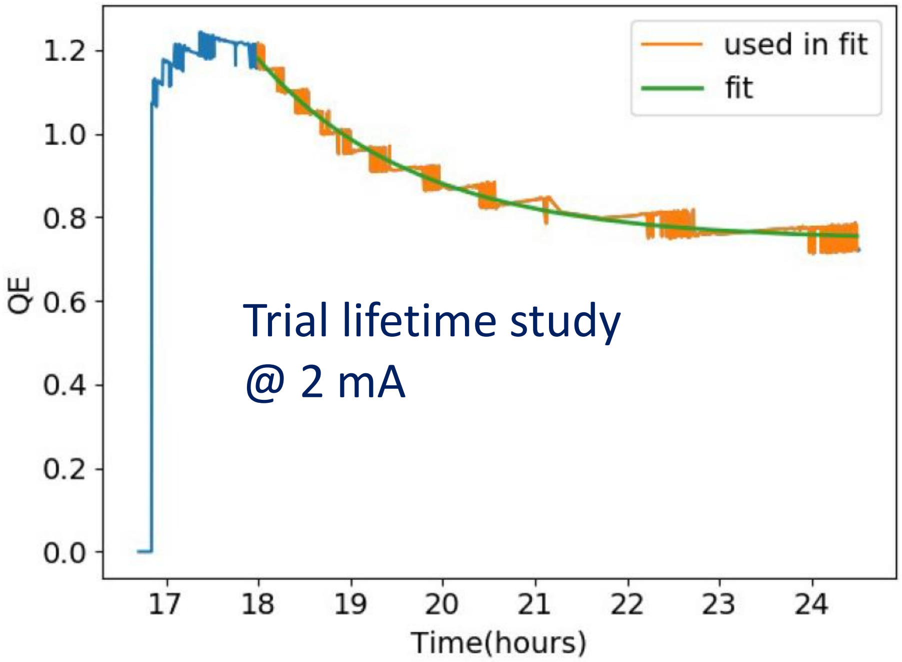
>25 W in the visible (ML)

>7 W in the UV (ML)

Currently facility water limits laser output. To be addressed with dedicated HX in the Jan 2022



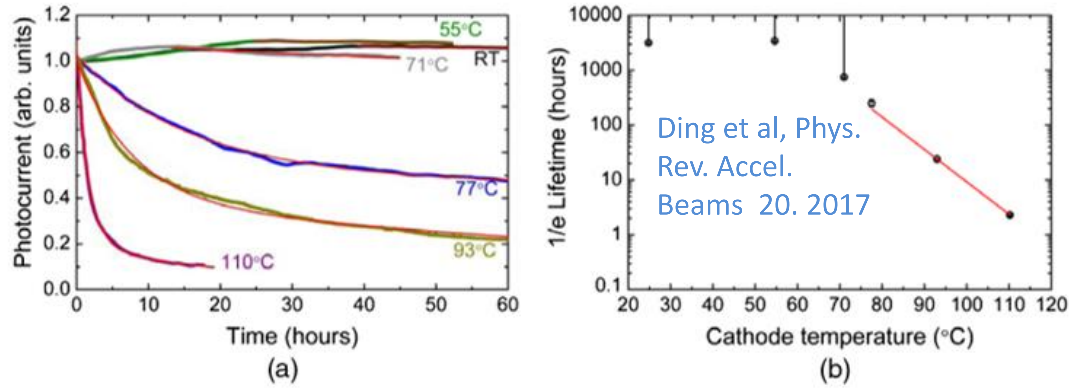
High current commissioning



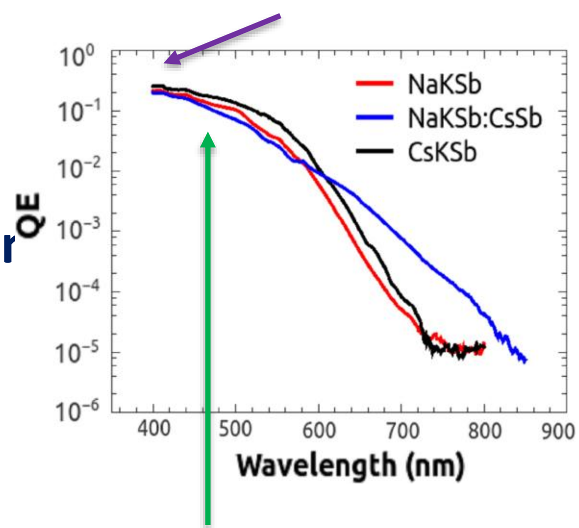
- **Gun current ramped in stages with approvals at each step from CLASSE internal safety committee**
- **Radiation surveys and remote diagnostics used to update lead shielding**
- **10 mA beam current at 200 keV achieved—suitable for lifetime studies!**

Vis/UV Alkali operation

- **Operate alkali antimonides in the near UV:**
  - **351 nm from cw Ar ion laser**
- **We aim at improving the efficiency of the photo-extraction process and decrease the heat load on the cathode:**



IR to UV => efficiency 0.3
UV to e- => efficiency 0.25



IR to VIS => efficiency 0.6
VIS to e- => efficiency 0.07

IR to UV to e- => ~8%
IR to Vis to e- => ~4%

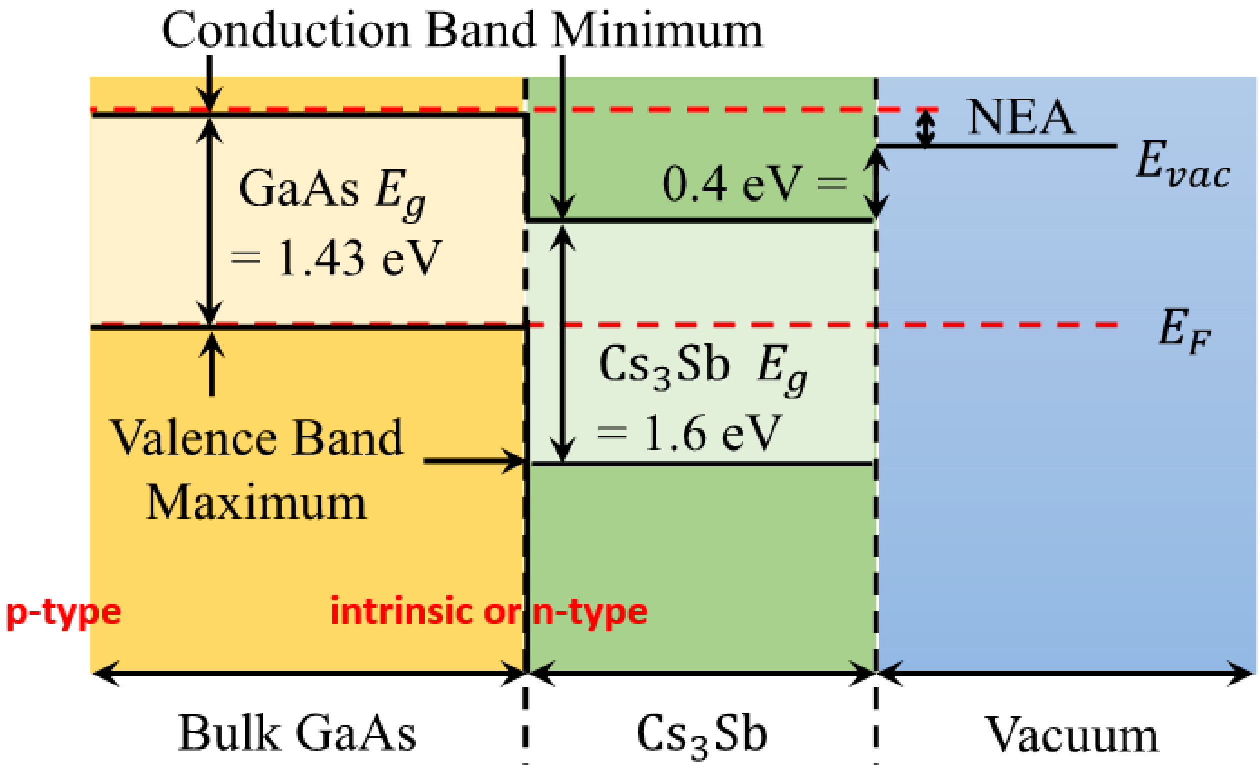
- For the **same avg. current** we need **half of the UV laser power w.r.t. VIS**;
- Power heat losses on the cathode are **reduced by 65%;**

Vis/UV Alkali status

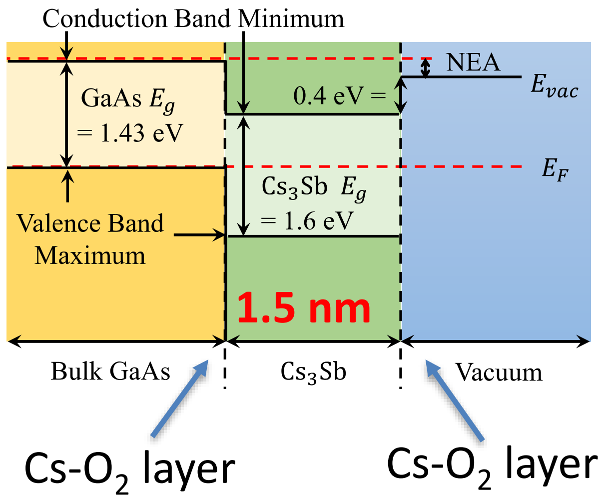
- **Commissioning of HERACLES was done with visible light (470 nm) illumination on a Cs_3Sb photocathode where 10 mA current was reached**
- **After commissioning, a trial lifetime measurement at 2 mA was performed (milestone 1.1)**
  - **To minimize laser optics switching between Vis and UV, GaAs studies will be completed before milestone trying UV illumination**
  - **Will repeat lifetime measurement in the visible before UV swap to ensure meaningful comparison.**

GaAs coatings tests

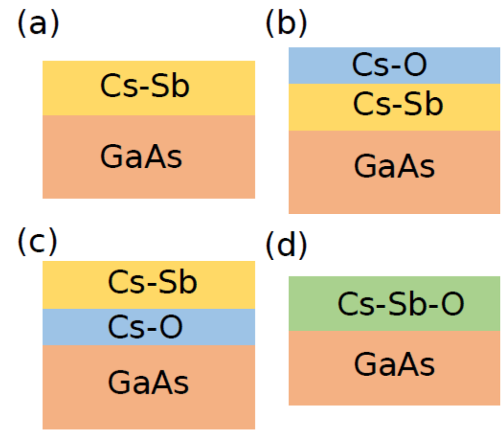
- **Negative Electron Affinity (NEA) activation of GaAs occurs when Cs+Oxidant (O_2,NF_3) forms strong dipole layer on the surface.**
- **Extreme sensitivity to vacuum level as activation layer is typically a weakly bonded monolayer.**
- **Cs_3Sb can also cause NEA:**
  - **Less reactive than Cs-O**
  - **Thicker layer is more robust to ion back-bombardment**

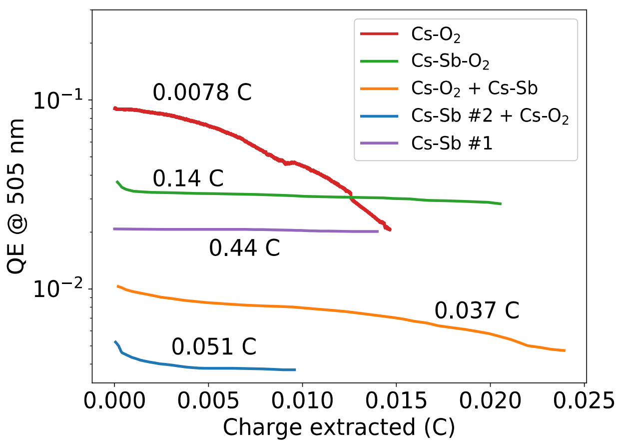


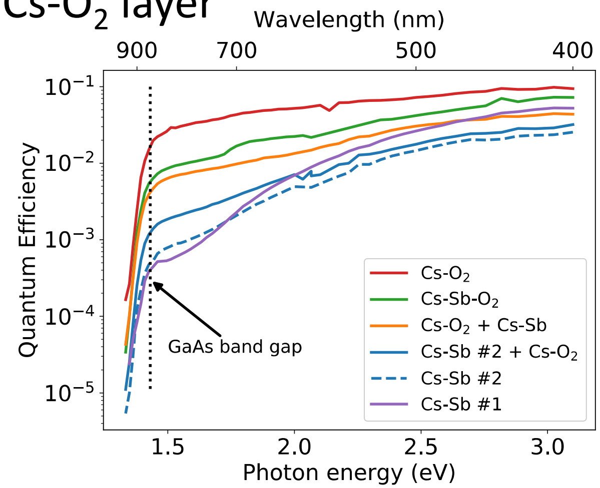
Cs_3Sb on GaAs - Methods



Various unconventional NEA activation layers on GaAs were studied







All the methods allowed reaching NEA conditions

Co-deposition of Cs-Sb-O_2 shows:

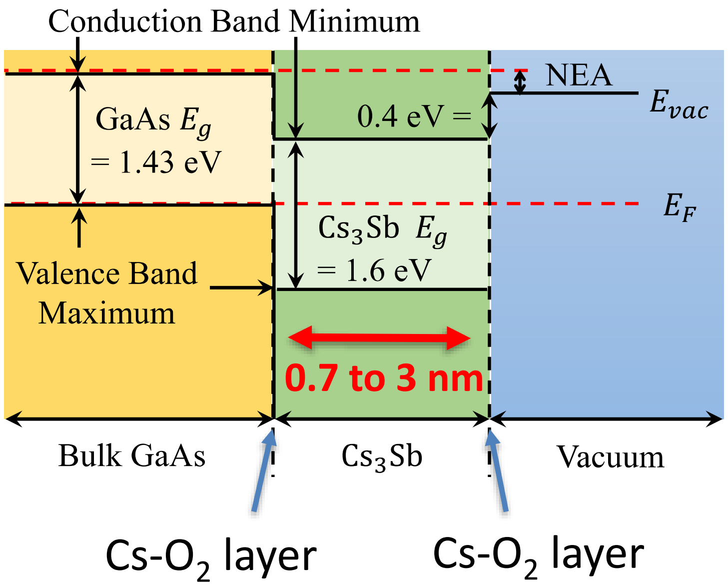
- **the longer lifetimes (x20)**
- **and the highest QE**

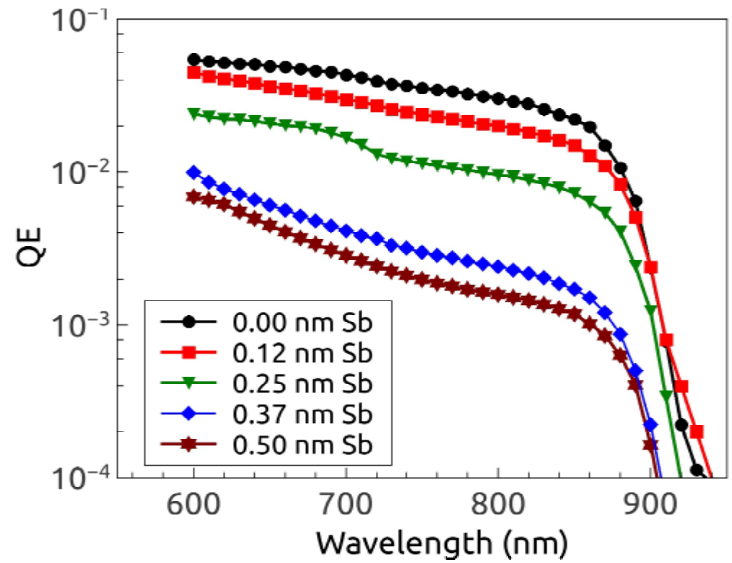
Improved lifetime of a high spin polarization superlattice photocathode

Jai Kwan Bae, Alice Galdi, Luca Cultrera, Frank Ikponmwen, Jared Maxson, and Ivan Bazarov

Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University, Ithaca, NY 14853, USA

Cs_3Sb on GaAs – Thickness studies





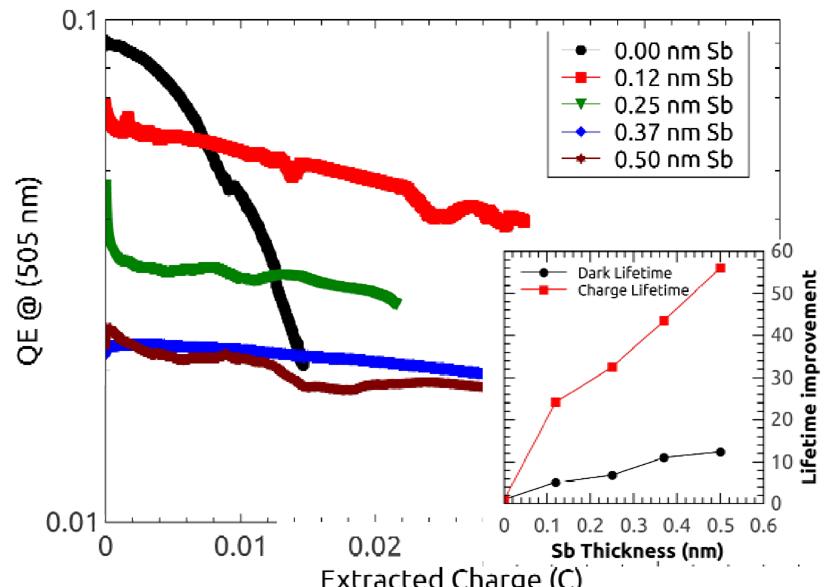
as we increase the layer thickness:

- **QE decreases and Lifetime increases**
- **0.12 nm layer may increase charge lifetime 25X over Cs-O activation**

Long lifetime polarized electron beam production from negative electron affinity GaAs activated with Sb-Cs-O: Trade-offs between efficiency, spin polarization, and lifetime

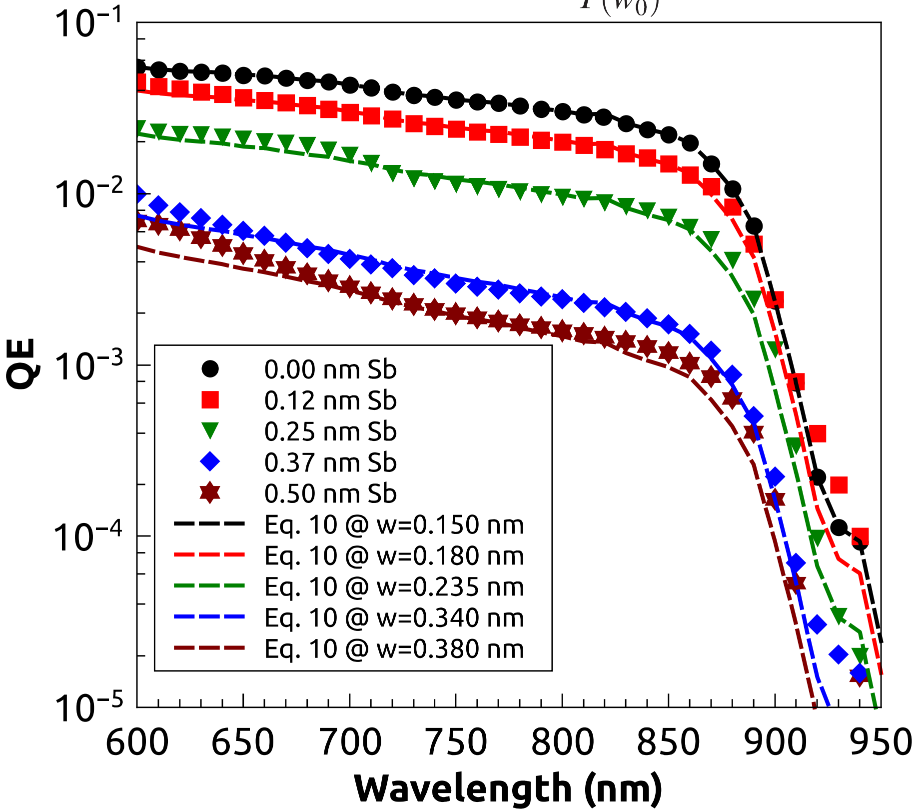
Luca Cultrera*, Alice Galdi, Jai Kwan Bae, Frank Ikponmwen, Jared Maxson, and Ivan Bazarov

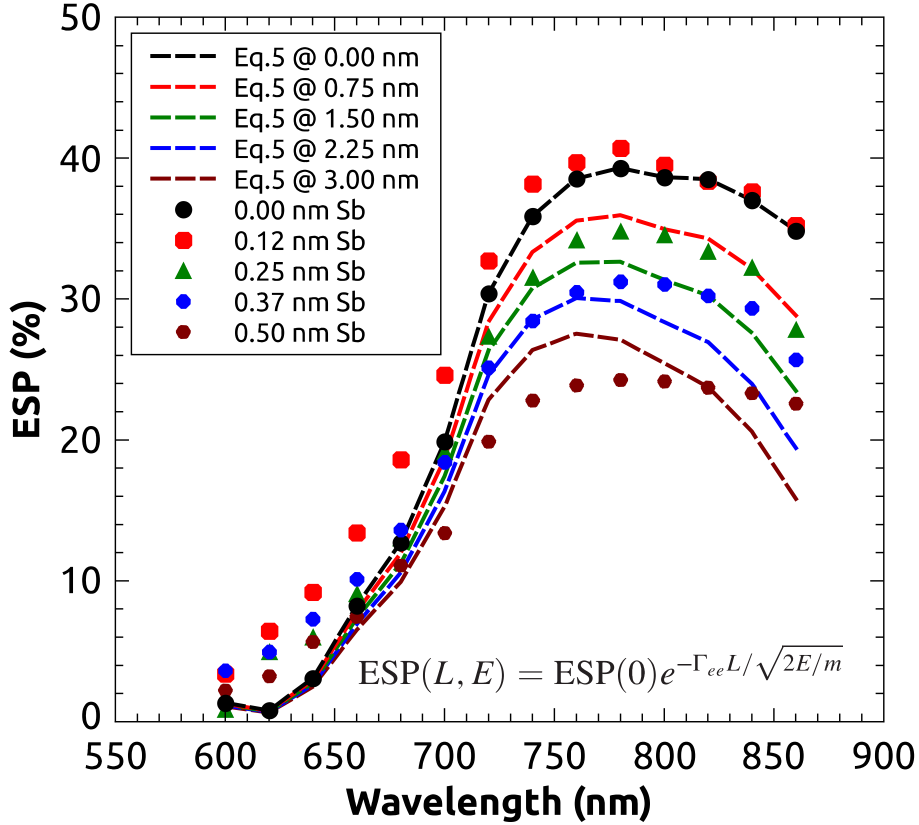
Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University, Ithaca, New York 14853, USA



Spin polarization

$$QE(w_{Cs_3Sb}) = QE_0 \frac{T(w_{Cs_3Sb})}{T(w_0)}$$





$$\mathrm{ESP}(L,E) = \mathrm{ESP}(0)e^{-\Gamma_{ee}L/\sqrt{2E/m}}$$

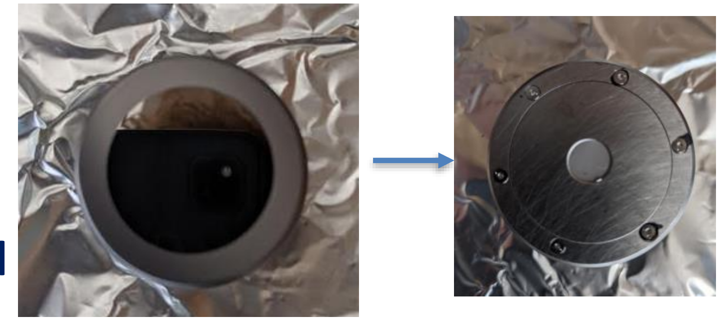
@780 nm **Spin polarization is essentially preserved (up to ~0.1 nm thickness)**

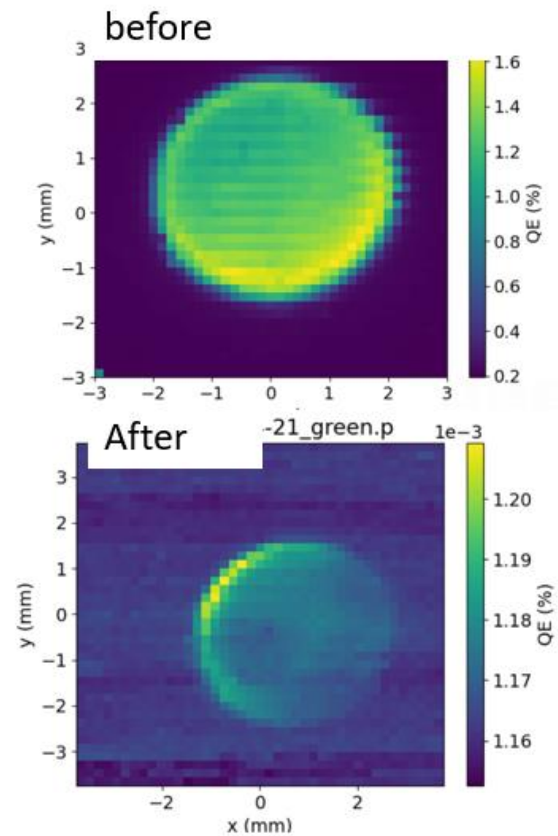
L. Cultrera et al., Phys. Rev. Accel. Beams **23** (2020) 023401

Status of GaAs studies

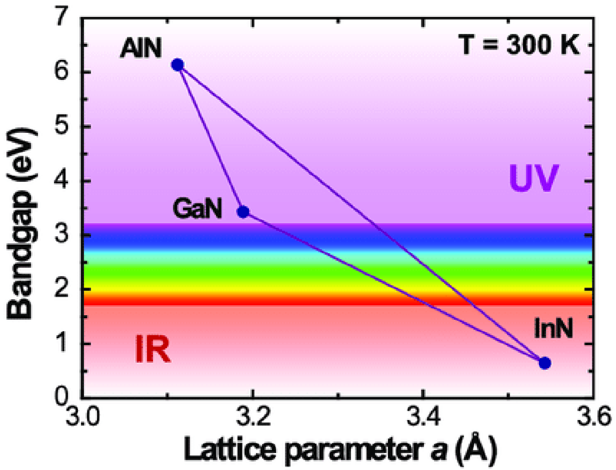
Currently running a campaign to finish tasks related to Cs Sb O test in the DC gun.
We have:

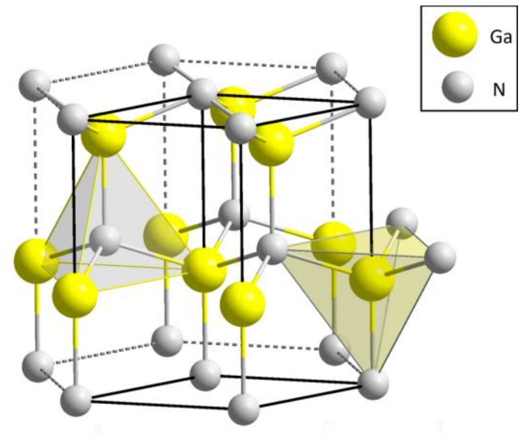
- **Performed a lifetime measurement Cs-O activated GaAs to serve as the baseline to compare with robust coating.**
- **installed a new UHV chamber attached to gun storage for more repeatable QE mapping.**
- **Successfully used a new (to our gun) sample puck that allows us to mount GaAs off-centered. It allows:**
    - **Off centered cathode growth without masking.**
    - **Smaller active area eliminates unwanted emission from back scattered laser light-→ cleaner vacuum in the gun, more likely to see cathode lifetime related to ion-back bombardment.**



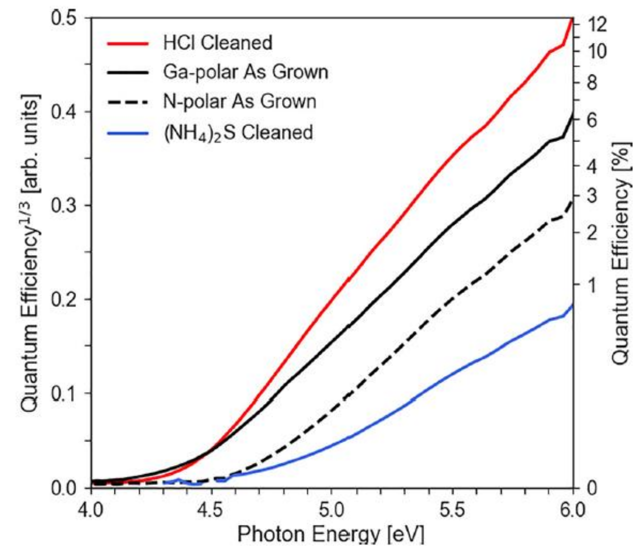


GaN photocathodes





Wurzite (hexagonal) GaN

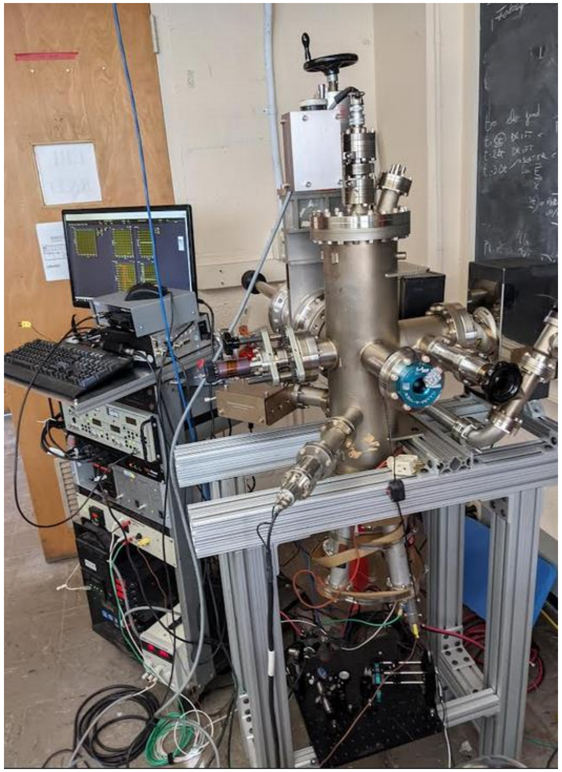


- **For photoemission near the bandgap (3.5 eV) GaN requires NEA**
- **Typically, NEA is achieved with Cs making it sensitive to vacuum poisoning**
- **Recently NEA activation of AlGaN was achieved and found to be qausi-airstable producing comparable QE to cesiated GaN**
- **Excellent thermal stability and thermal conductivity: great high current candidate!**

Polarization engineered N-polar Cs-free GaN photocathodes

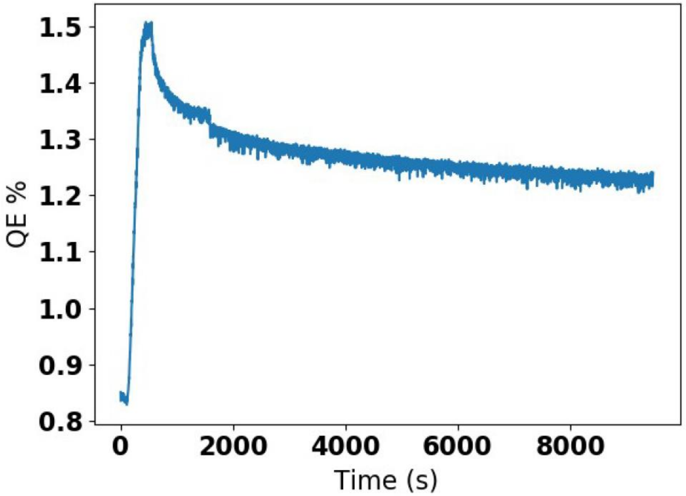
Jonathan Marini,[1,a)] Isra Mahaboob,[1] Emma Rocco,[1] L. D. Bell,[2] and F. Shahedipour-Sandvik[1]
[1]*Colleges of Nanoscale Science and Engineering, SUNY Polytechnic Institute, Albany, New York 12203, USA*
[2]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA*

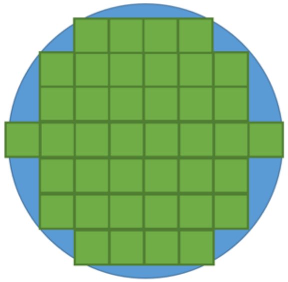
GaN studies status



Dedicated GaN activation chamber complete!

- NEA activation with Cs
- CsI (Alkali Halide) source





- New sample holder tested in DC gun at 200 keV. No measurable field emission!
- Compatible with III-nitride samples
- All milestones complete for this task!

Budget and Deliverables

	FY21	FY22	Total
a) Funds allocated	184 k	184 k	368 k
b) Actual cost to date	115 k	15 k	130 k

Funds

preparation

Lifetime in HERACLES

Task completed

Remaining timeline

Calendar year 2022	1st quarter	2nd quarter	3rd quarter	4th quarter
Task 1 (Vis/UV Alkali antimonide)				
Task 2 GaAs studies				
Task 3 GaN Chamber Fab.				
Task 4 GaN lifetime				

Thank you for your attention!

BACKUP SLIDES

Tasks and milestones

TASK 1:Operate the photogun and beamline with alkali antimonide photocathodes at the highest possible beam current and study the effect of the laser heating as limiting effect on the cathode lifetime.

- **Milestone 1.1**:Operate alkali antimonide photocathodes with visible laser light in the beamline with ion clearing electrodes and measure the photocathode lifetime as function of the average current level and laser power.
- **Milestone 1.2**:Operate alkali antimonide photocathodes with UV laser light in the beamline with ion clearing electrodes and measure the photocathode lifetime as function of the average current level and laser power. Compare results with the ones obtained with visible laser light.

TASK 2:Test of GaAs-based photocathodes for spin polarized electron beam activated with Cs_2Te and Cs_3Sb at the highest possible beam current and studies of the effect of ion back bombardment on the operational lifetime.

- **Milestone 2.1**:Cs2Te and Cs3Sb activated GaAs-based photocathode will be prepared with our optimized procedures in the photocathode laboratory and moved using a vacuum suitcase to the photogun load lock. QE characterization will be performed during every step of the move to verify the cathodes will survive the move.
- **Milestone 2.2**: the Cs2Te and Cs3Sb activated GaAs-based photocathodes will be loaded into the photogun and we will measure the operational lifetime as function of the average current. Comparison will be made with GaAs photocathodes activated to NEA using the Cs-O “yo-yo” method and operated at identical conditions.

Tasks and milestones

TASK 3:Design and build the hardware: a new cathode holder and a dedicated activation chamber-required to operate III-nitride photocathodes in the photogun.

- **Milestone 3.1**:design,build and gun test a new photocathode gun sample holder, compatible with the high fields of the DC photogun and can support the operation of III-nitrides and more in general small size samples(6x6 mm2).
- **Milestone 3.2**:we will repurpose existing hardware to build and commission a vacuum chamber dedicated to the alkali halides activation of III-Nitride which can interface with our existing vacuum suitcase.

TASK 4:III-nitride materials in their stable wurtzite structure (based on GaN and InGaN) will be tested and characterized as photo-emitters in the photocathode lab and in the photogun.

- **Milestone 4.1**: Design and procure candidate III-nitride layered structures based on their wurtzite phase that can be used as photocathode in the near UV or VIS range of the spectrum.
- **Milestone 4.2**:Perform extensive test on III-nitride layered structure at low field and average current in the photocathode lab and in the photogun at high field and high average current comparing the performance achieved with different methods for the NEA activation (Cs, alkali halides, N-polar Cs free activation)