High current electron sources for strong hadron cooling and polarized sources for EIC

Luca Cultrera

Outline

- Motivation;
- State-of-the-art;
- Photocathode R&D at Cornell University;
- Cs-Sb-O activated GaAs and SL;
- HV Gun and beamline status;

EIC report relevance and budget

High current electron sources for strong hadron cooling and polarized sources for EIC

Row	Proponent	Concept		Panel priority	Panel sub-priority
2	Panel	ALL	High current single-pass ERL for hadron cooling	High	A
7	Panel	LR	High current polarized and unpolarized electron sources	High	B

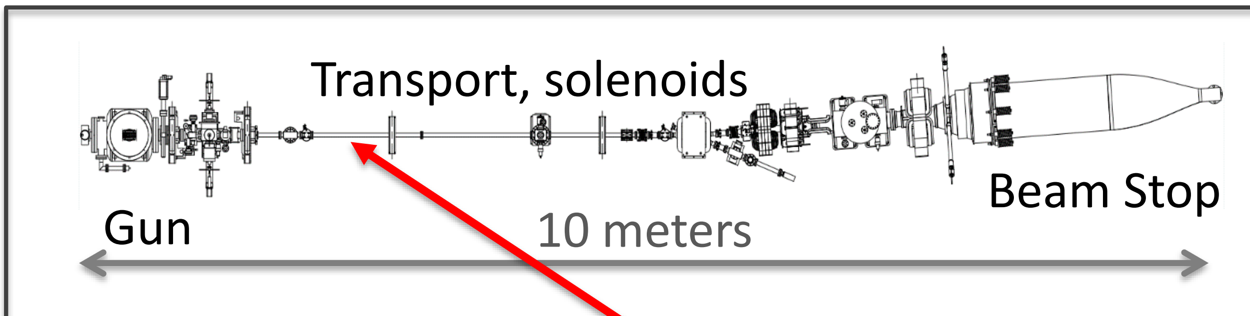
	FY12+F13	FY14+F15	FY16+F17	FY18+F19	Totals
a) Funds allocated			280,000	338,000	618,000
b) Actual costs to date			280,000	214,226	494,226

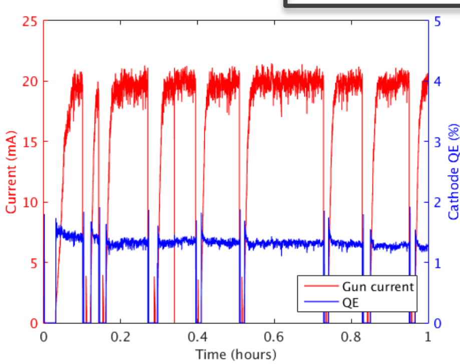
Tasks and milestones

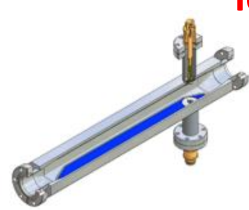
- **Task 1: Resurrect the beamline** dedicated to study the operation of the electron source up to 100 mA level by leveraging existing hardware, including a 75kW electron beam stop.
  - **Milestone 1.1:** Perform numerical simulations aimed at finding a beamline configuration that allows the transport of bunched beams with 1 nC charge per bunch from the gun to the beam dump.
  - **Milestone 1.2:** Assemble and recommission the beam line according to simulation to perform the experimental tasks here proposed.
- **Task 2: Upgrade the DC gun with a clearing electrode near the anode** to benefit the photocathode lifetime by repelling the ions coming from the downstream of the beamline.
  - **Milestone 2.1:** Design, build and install a special clearing electrode that can be installed without breaking the gun vacuum in a near proximity of the gun anode.
  - **Milestone 2.2:** High voltage processing of the gun.
- **Task3:** Integrate into the beamline the already available ion clearing electrode structures enable studies of secondary ions production and corresponding clearing techniques in the presence of high intensity electron beams in order to elucidate their role on the stability of the electron source and photocathode lifetime.
  - **Milestone 3.1:** Ion clearing electrodes will be installed along the beamline based on the results from numerical simulations;
  - **Milestone 3.2:** Study the effect of clearing the ions and along the beamline and near the gun on the electron source stability and cathode lifetime.
- **Task4:** Perform **high current tests** aimed at production of bunch charges and average currents relevant for strong hadron cooling application using tunable wavelength laser allowing us to explore photocathodes in new parameter space.
  - **Milestone 4.1:** Build an optical transport line for the laser that allows to operate in the visible range of the spectrum (down to ~400 nm) using achromatic lenses and broadband mirrors.
  - **Milestone 4.2:** Using already known photocathodes explore the possibility of extending the lifetime of the existing photocathodes by using non-conventional laser photon energies only in the visible range of the spectrum.
- **Task 5:** A fully equipped photocathode laboratory and other campus facilities will be used to **grow and characterize new promising robust photocathode materials** for the production of un-polarized and polarized electron beams.
  - **Milestone 5.1:** Procure and/or synthesize new promising candidate materials for the production of high average current and perform the characterization of their photoemission properties in the visible range of the spectrum.
  - **Milestone 5.2:** Procure and/or synthesize new promising candidate materials for the production of highly polarized electron beam and perform the characterization of their photoemission properties (in the visible range of the spectrum.

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."

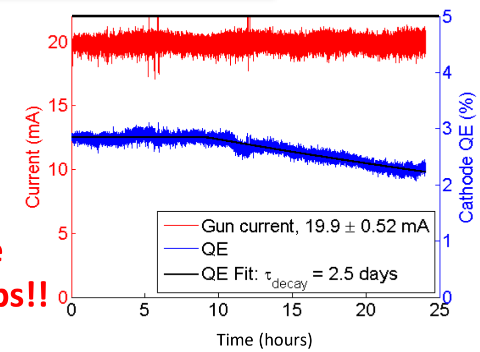






Ion Clearing Electrode

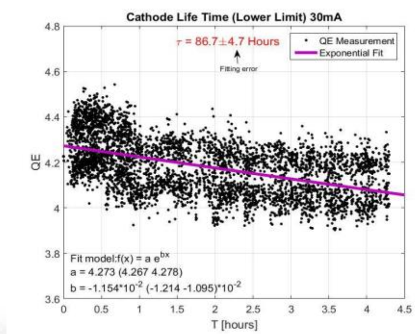
With ion clearing electrode
24 hours at 20 mA with no trips!!



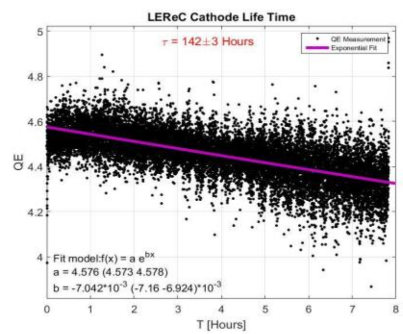
Low energy electron cooling @ BNL

Cathode lifetime in the gun: 2018

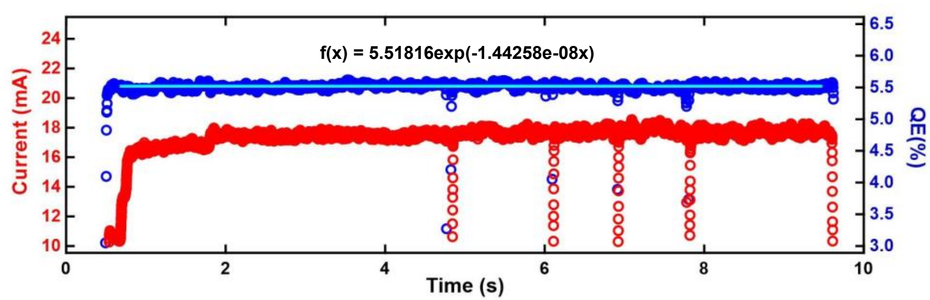
30 mA beam current, t = 87 h, QE > 4%



25 mA beam current, t = 142 h, QE > 4%



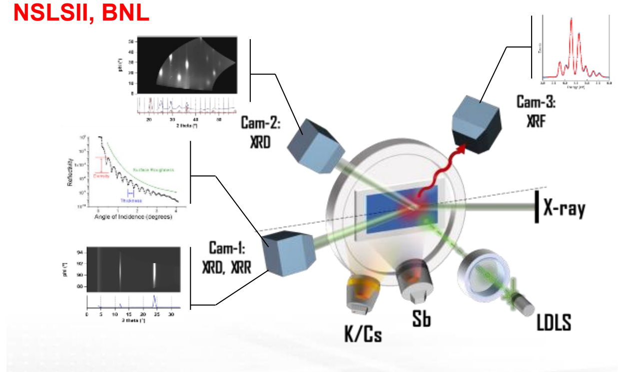
17mA beam current, QE =5.5 %,
infinite lifetime during CW operation

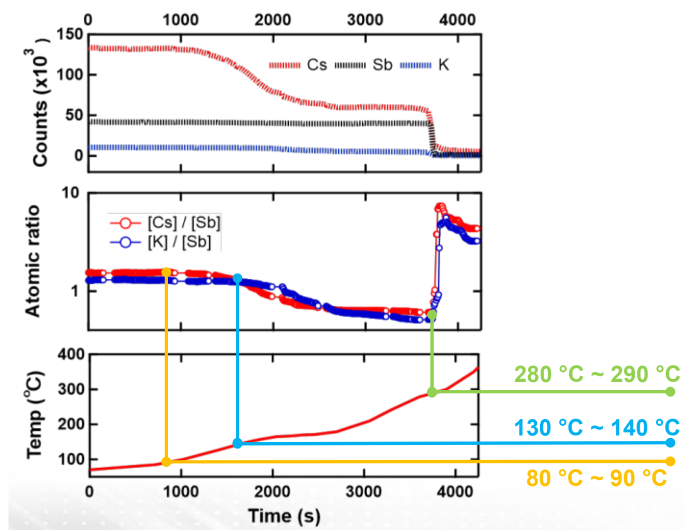


Alkali antimonide cathode heating induces QE degradation

Experimental setup:
***Operando* chamber**

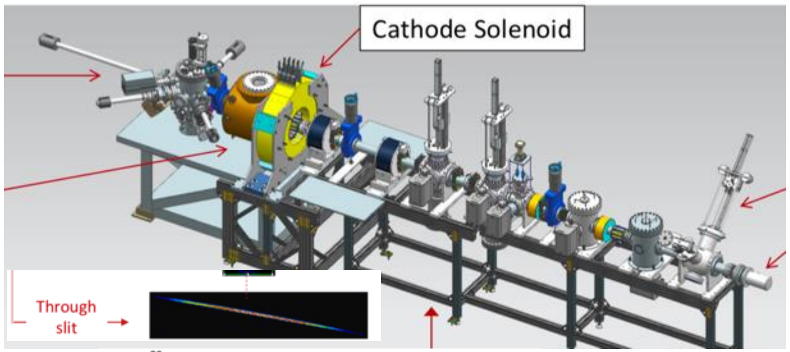
Beamline 4-ID,
NSLSII, BNL

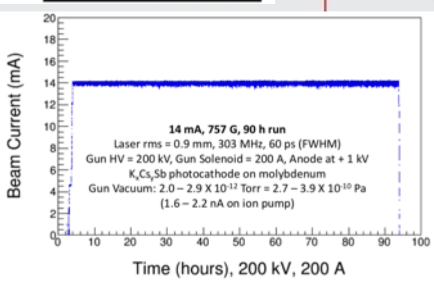


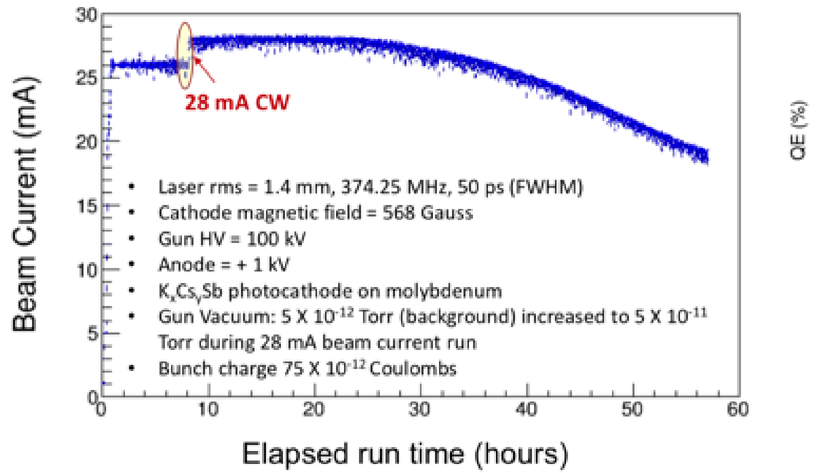


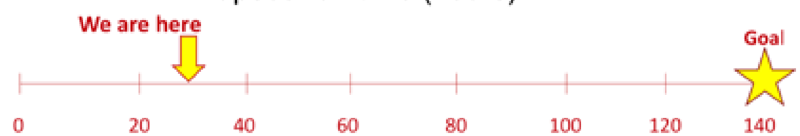
G. Mengjia, ERL'19

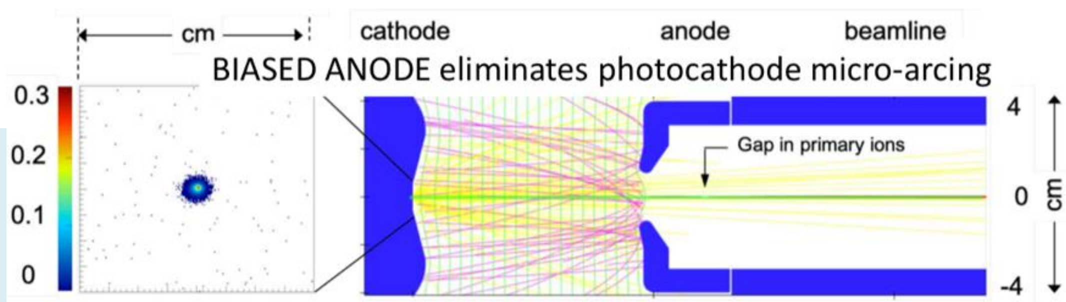
Magnetized beam generated from DC gun for JLEIC Electron Cooler







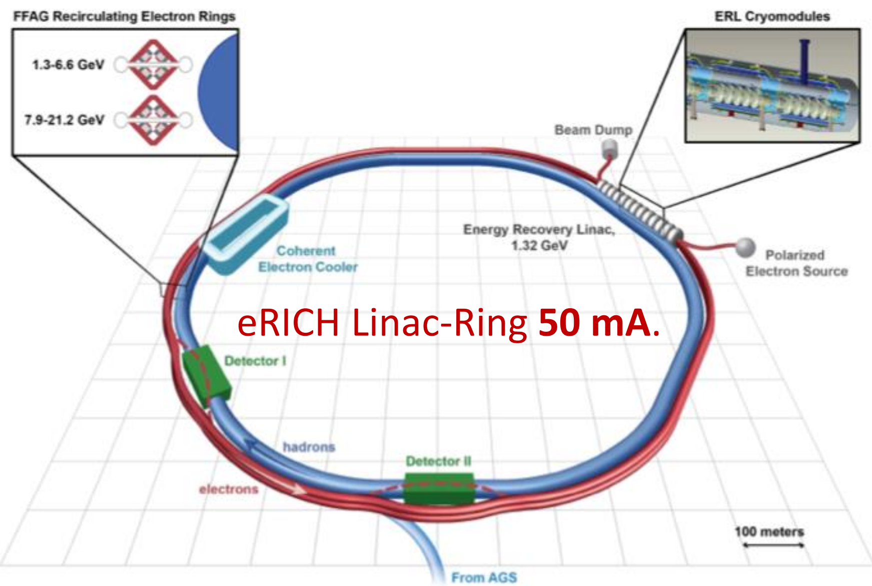




- Long lifetime at >10 mA, magnetized
- Bias anode is helpful
- To test thermionic gun

S. Benson, ERL’19

High current and spin polarization

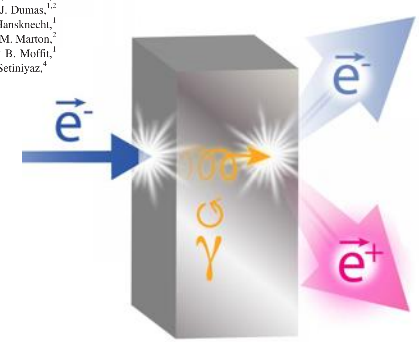


PRL **116,** 214801 (2016) PHYSICAL REVIEW LETTERS week ending 27 MAY 2016

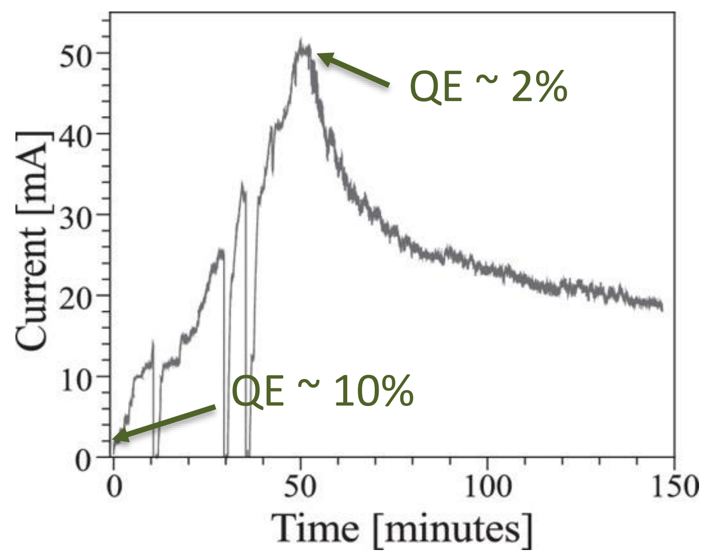
Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies

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]

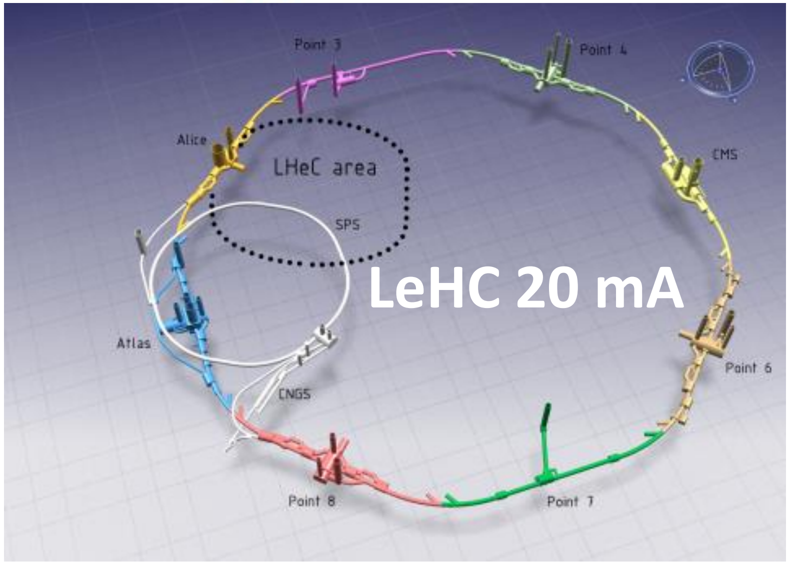
Several mA



GaAs @ 532 nm (~5 Watts)
200 Coulomb



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

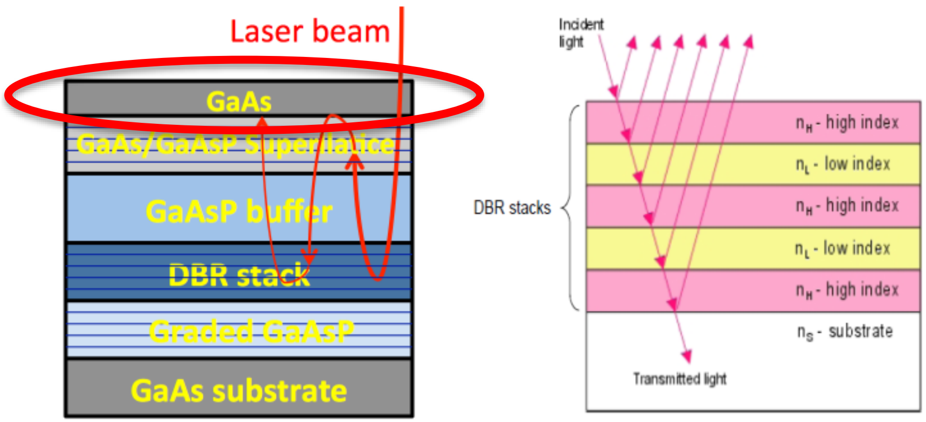


State-of-the-art SL-DBR

- *Total laser absorption in the SL layer is usually **<5%***
- *A DBR can be used to reflect the transmitted laser beam back to the SL*

Benefits of DBR

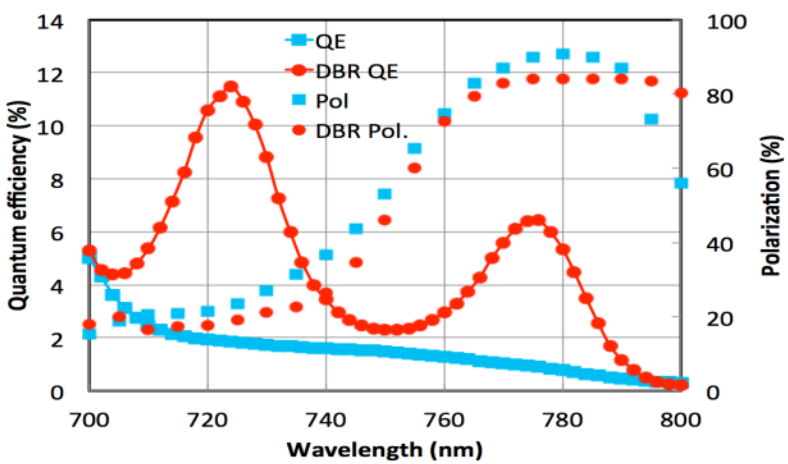
- DBR photocathode : absorpt. in GaAs/GaAsP SL >20%
  Less light needed ⇨ less heat deposited
- F-P can be formed btw top layer & DBR



S. ZHANG, P3 Workshop 2016, Newport News, VA — Jefferson Lab

Experimental Results

- non-DBR: QE ~ 0.89%, Pol ~ 92% @ 776 nm:
  - DBR: Pol. ~ 84%, QE ~ 6.4%, Enhancement: ~7.2



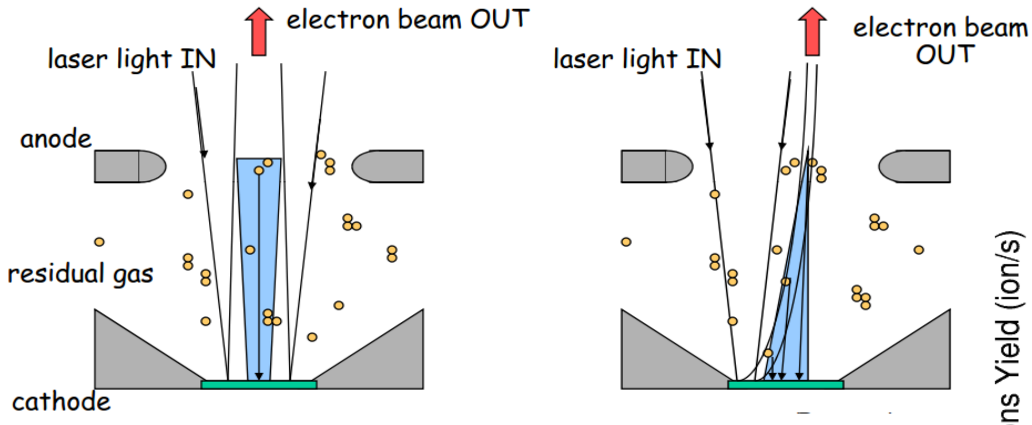
S. ZHANG, P3 Workshop 2016, Newport News, VA — Jefferson Lab

- ***QE is now a factor 6 larger***
- ***Potential for higher currents***
- *Less laser power, less heat to dissipate*
- *Quite complex structure*

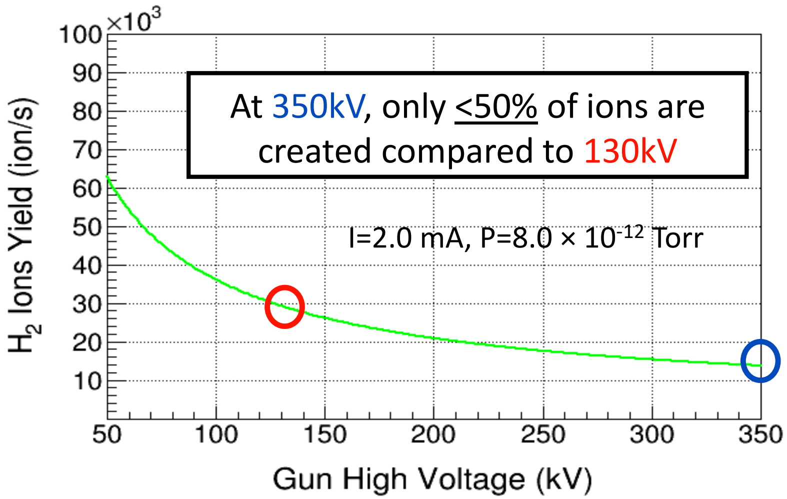
THE LAST LAYER IS A HIGHLY P-DOPED BULK GaAs ACTIVATED WITH Cs-O

But 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;

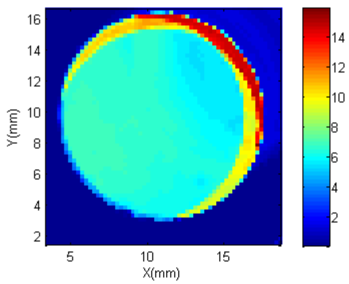


A single HV breakdown event inside the gun Can get the vacuum high enough to instantly "kill" the cathode

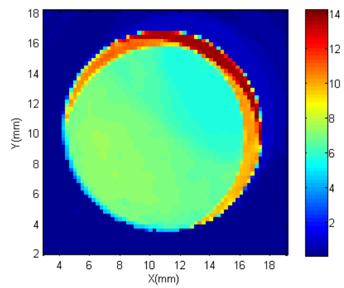


Courtesy of J. Grames

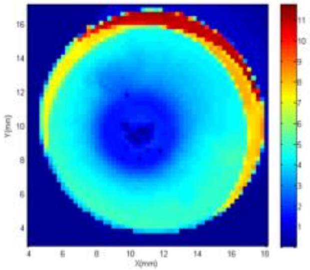
Alkali antimonides ion back bombardment



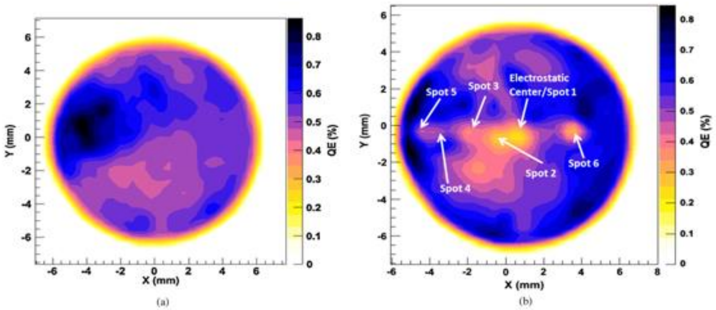
Fresh cathode

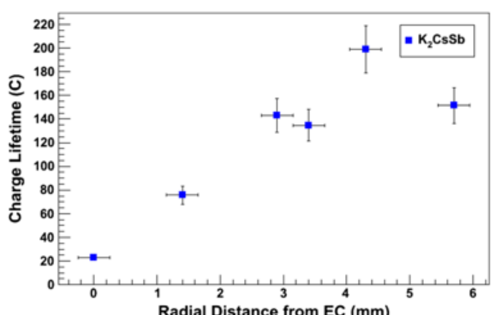


~10 mA
2 hours
No RF trips



~20 mA
2 hours
many RF trips

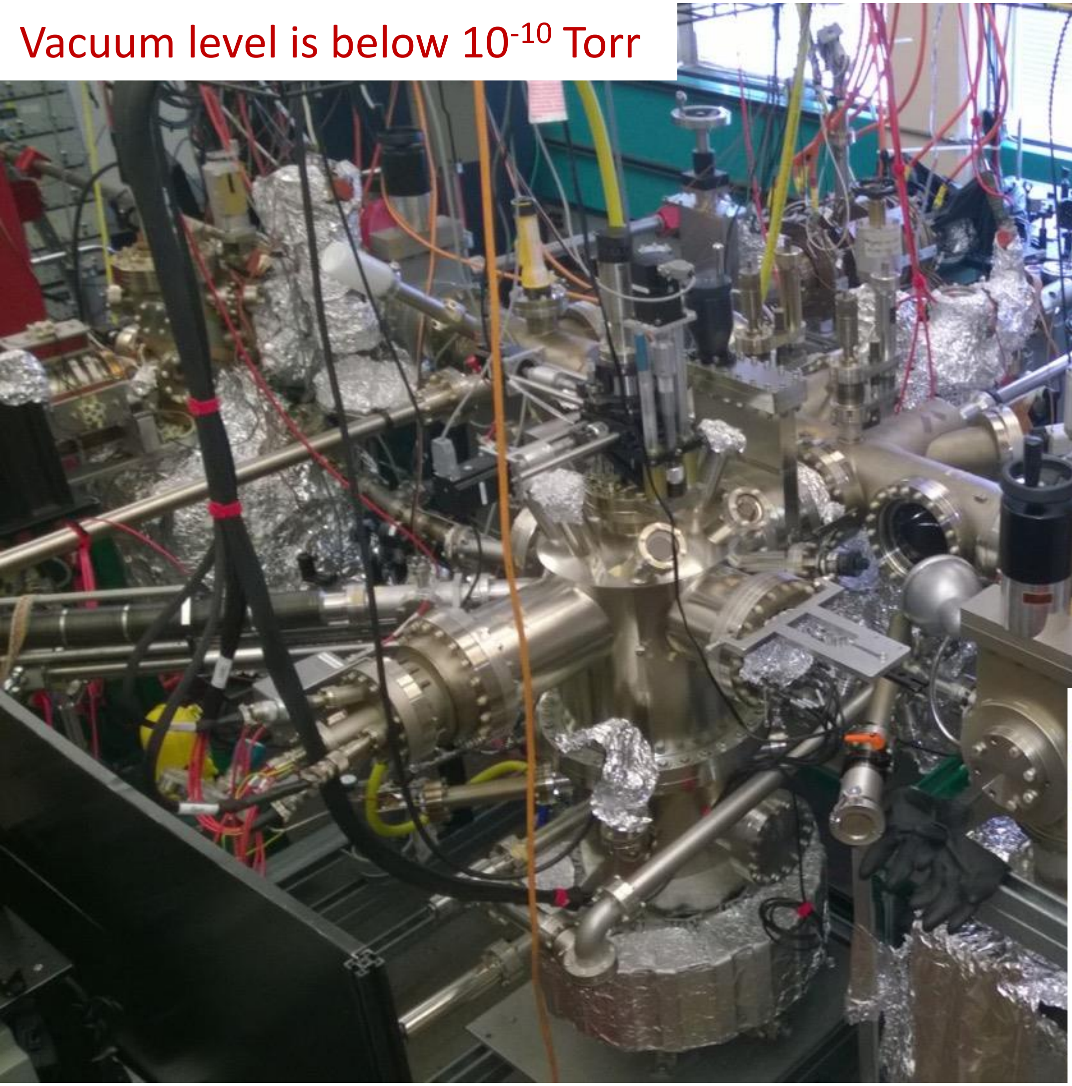


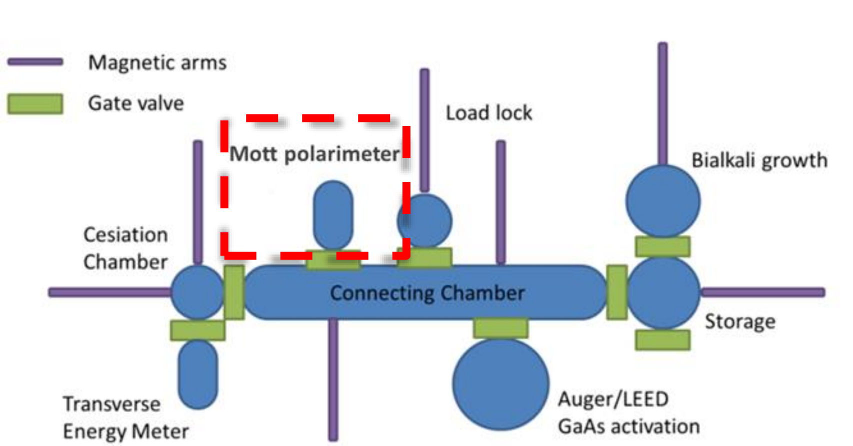


Stay away from the electrostatic center!

Cornell Photocathode Lab

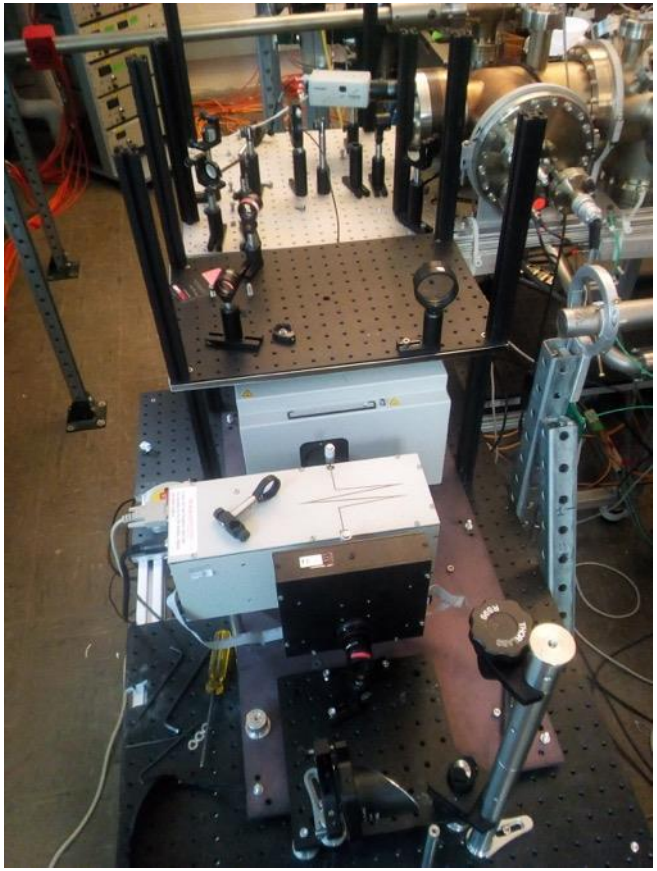
Vacuum level is below 10^{-10} Torr

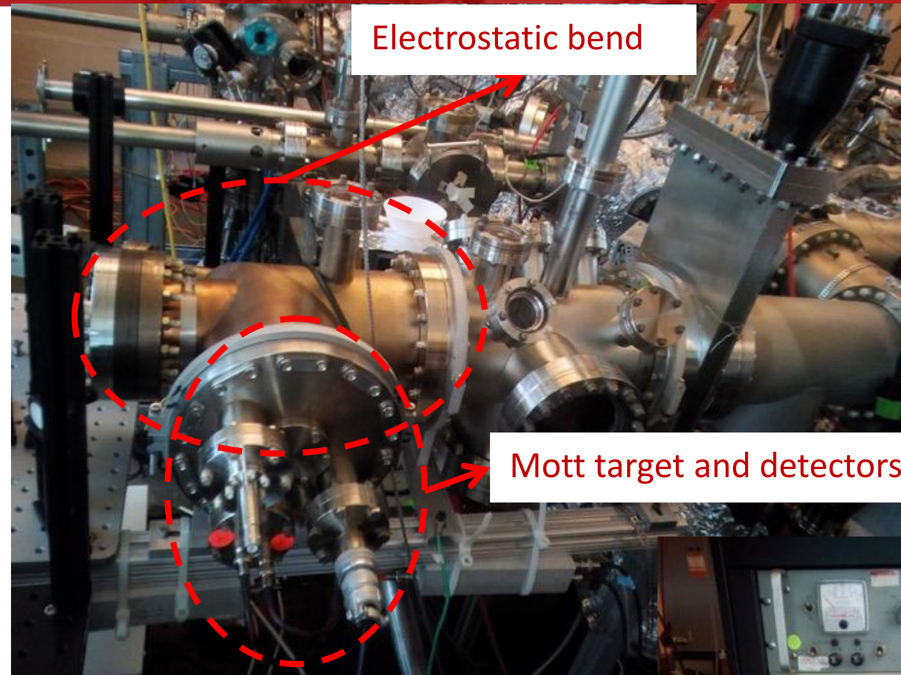




Mott polarimeter @ CU

Vacuum level is below 10^{-10} Torr



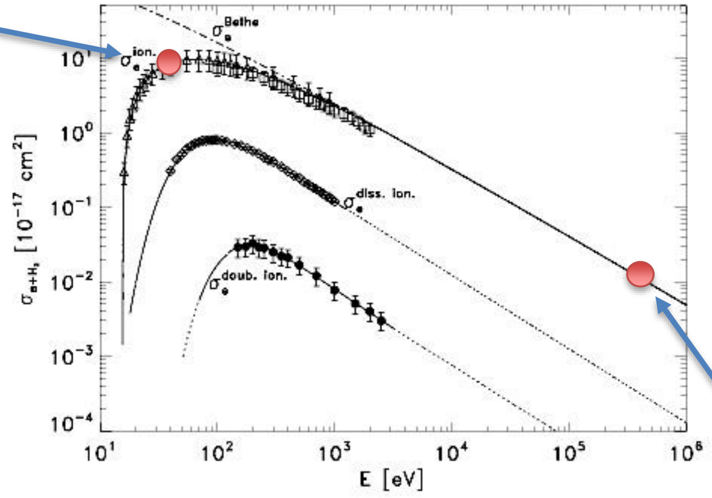


The retarding field Mott polarimeter has been refurbished upgraded and fully integrated into the photocathode lab UHV installation.

Thanks to M. Poelker and M. Stuzman for helping in debugging and setting up the polarimeter

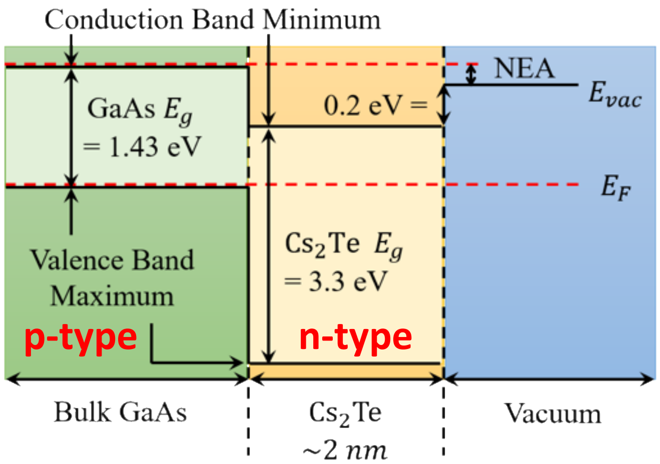
ESP results disclaimer

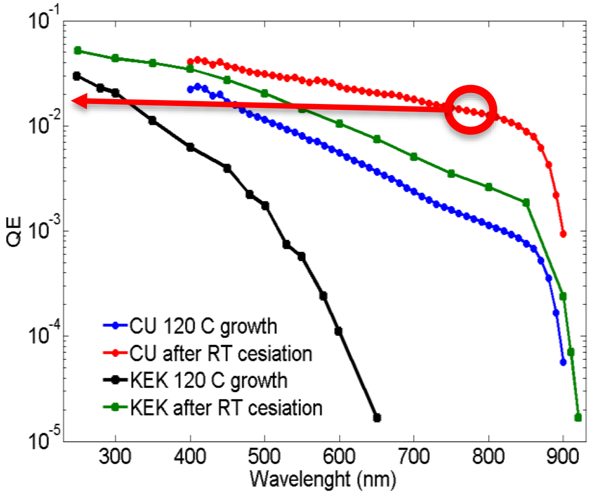
- Following measurements are performed:
  - At Very low electric field (bias -36 V);
  - With small cw laser diodes (tens of uW);
  - At vacuum levels of ~5×10^{-11} Torr;



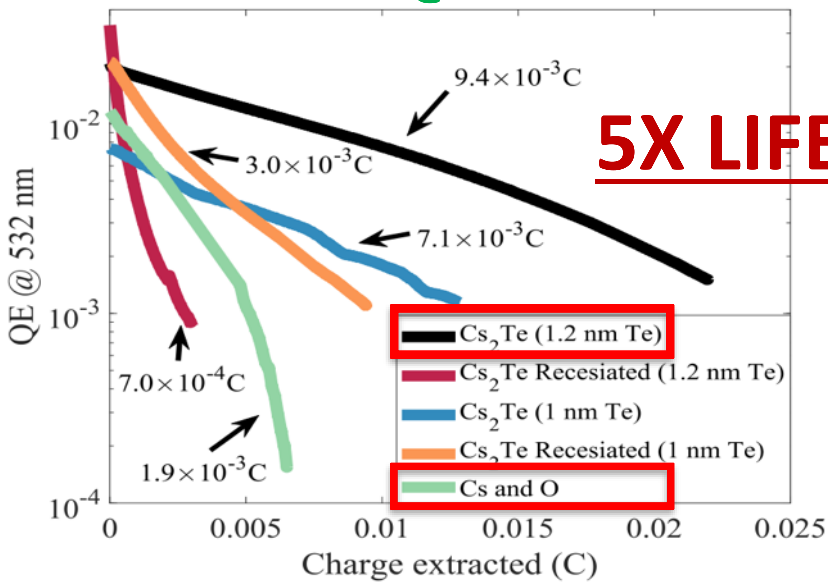
- About 3 order of magnitude larger probability to ionize hydrogen than in a real gun
- Due to low energy electron the ion back bombardment damage is likely to affect the very surface of our samples.

Cs_2Te on GaAs





@532 nm

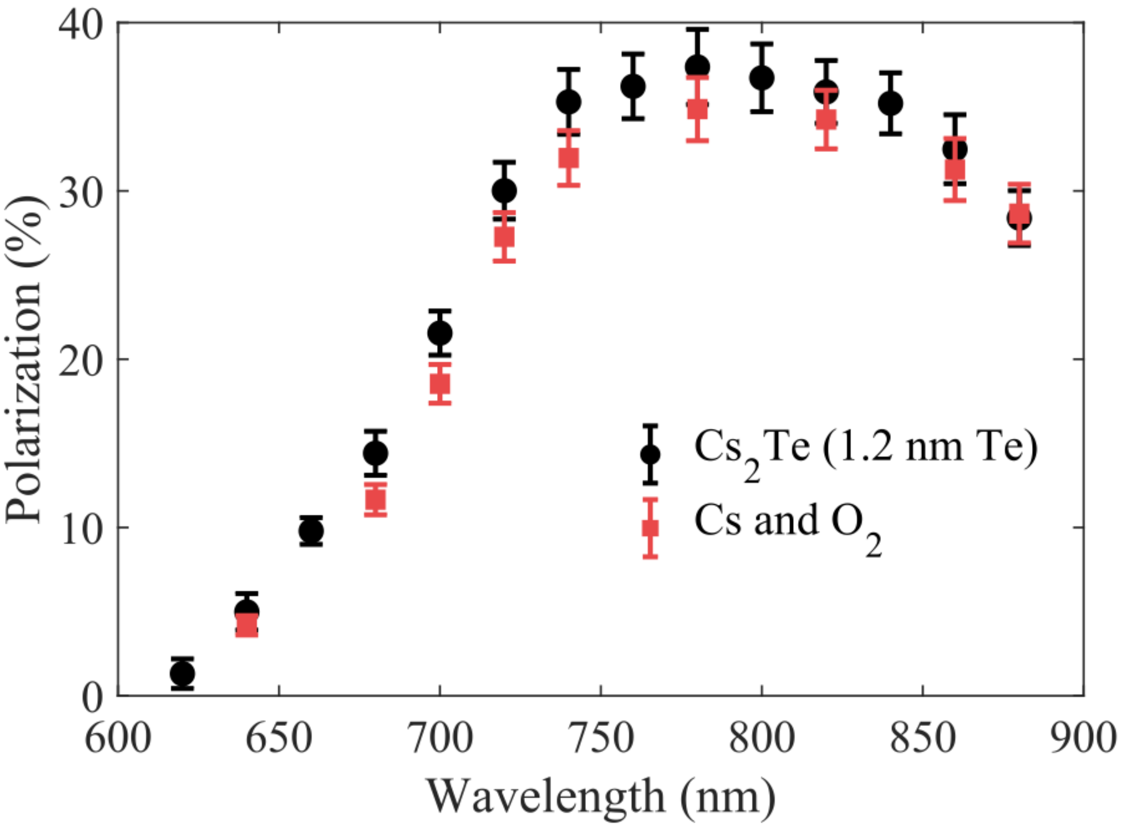


5X LIFETIME!

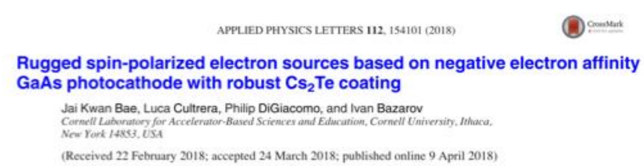
J. Bae et al., Appl. Phys. Lett. ***112*** *(2018) 154101*

Electron beam polarization

<u>The same bulk GaAs specimen</u> was activated first with Cs-O and later with Cs_2Te



Spin polarization is not affected by the Cs_2Te surface layer


APPLIED PHYSICS LETTERS 112, 154101 (2018)

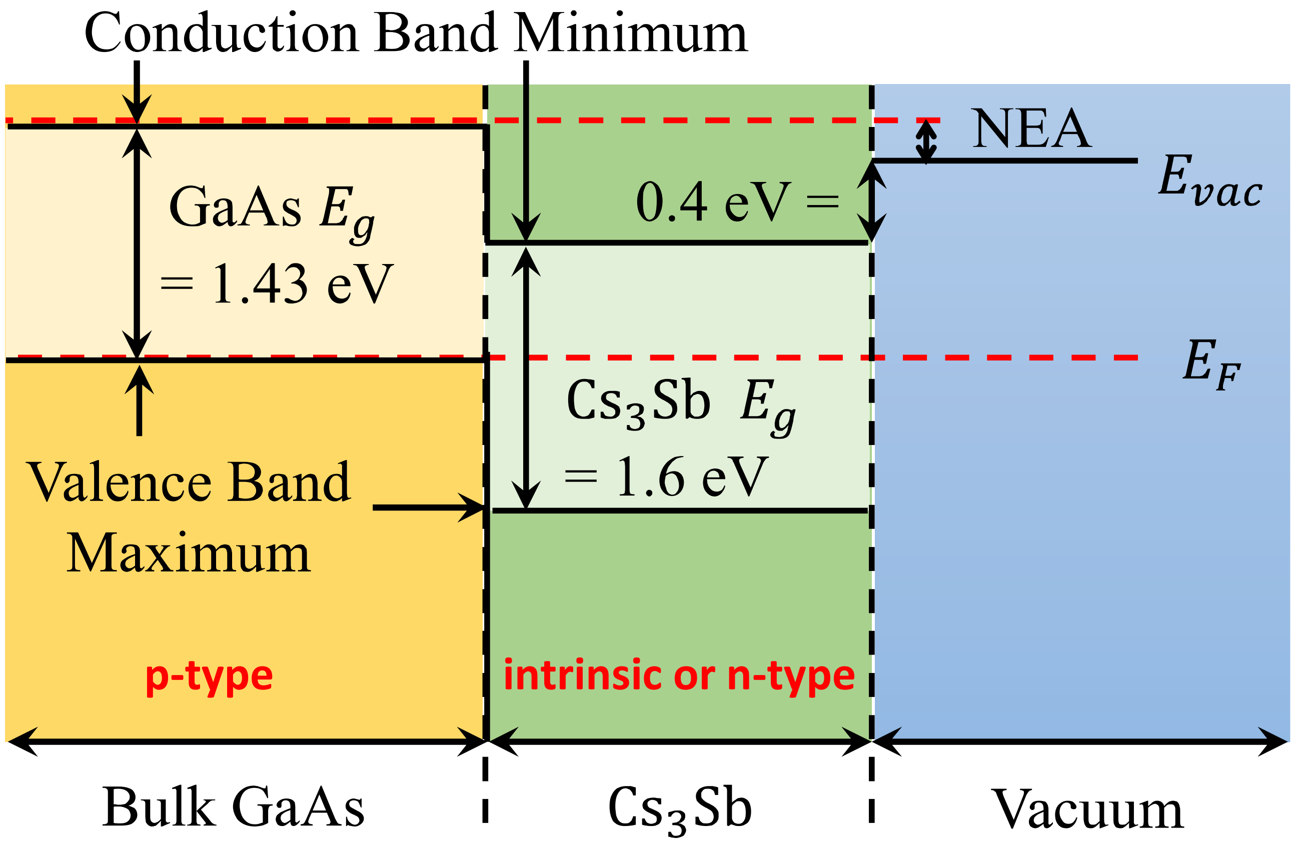
Rugged spin-polarized electron sources based on negative electron affinity GaAs photocathode with robust Cs_2Te coating

Jai Kwan Bae, Luca Cultrera, Philip DiGiacomo, and Ivan Bazarov
Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University, Ithaca, New York 14853, USA

(Received 22 February 2018; accepted 24 March 2018; published online 9 April 2018)

Cs_3Sb on GaAs

Doping control in alkali based photocathodes materials is difficult

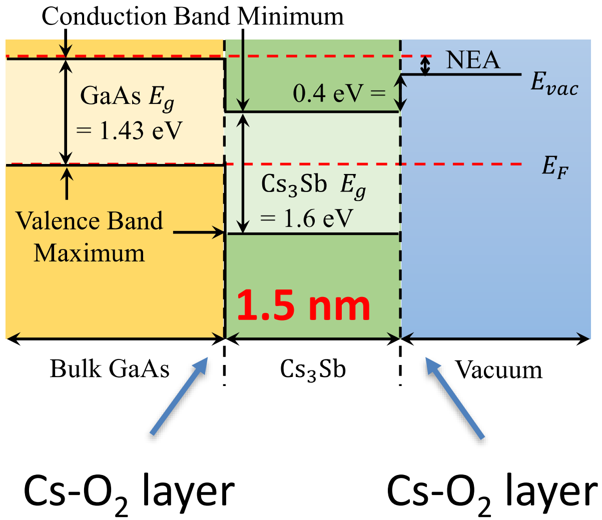


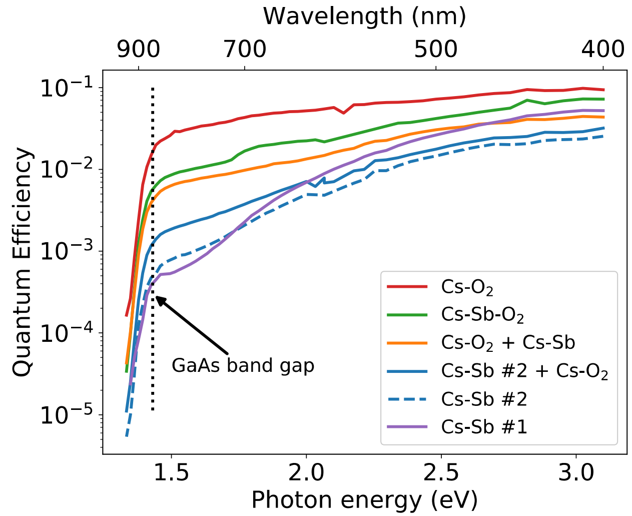
Doping character is controlled by the stoichiometry

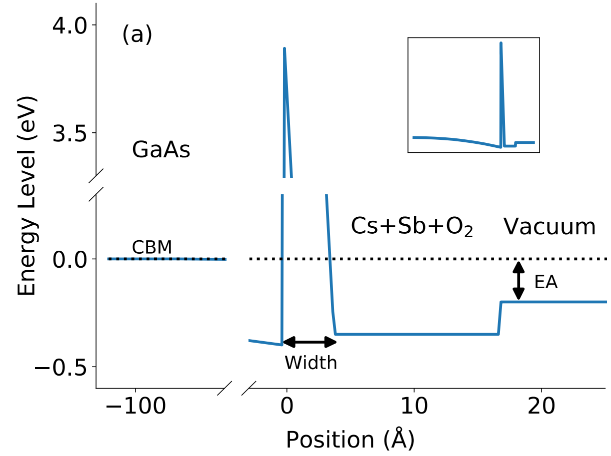
Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

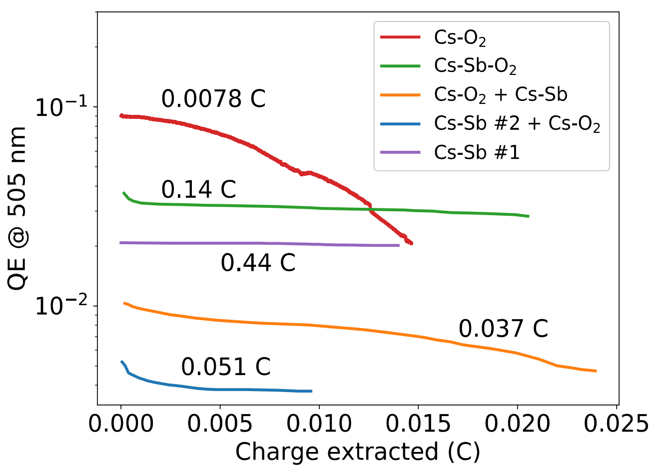
Cs_3Sb on GaAs - Methods

J. Bae et al, NAPAC 2019, MOPLH17



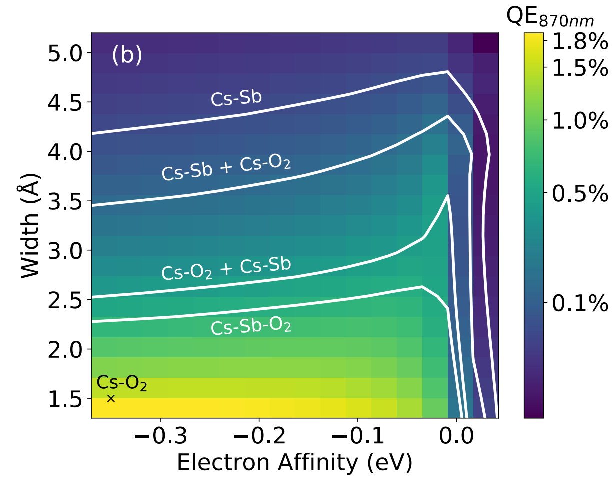




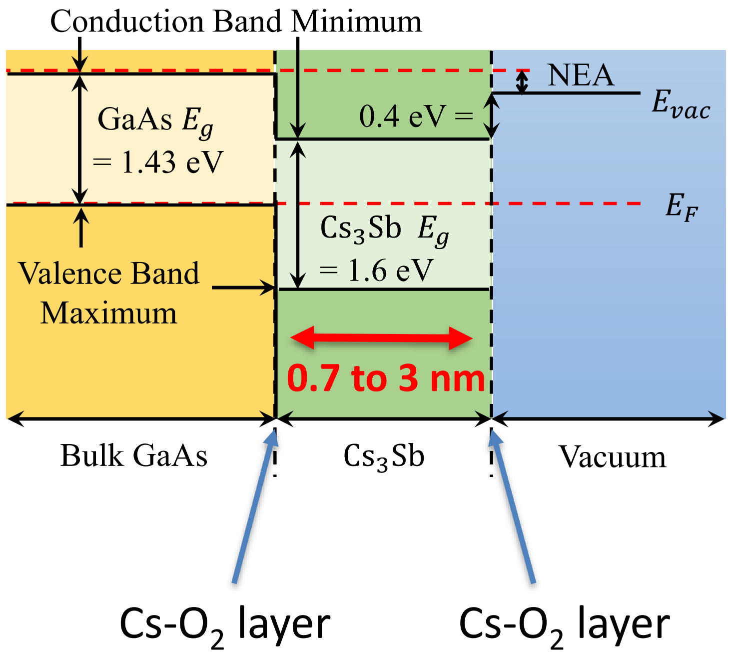


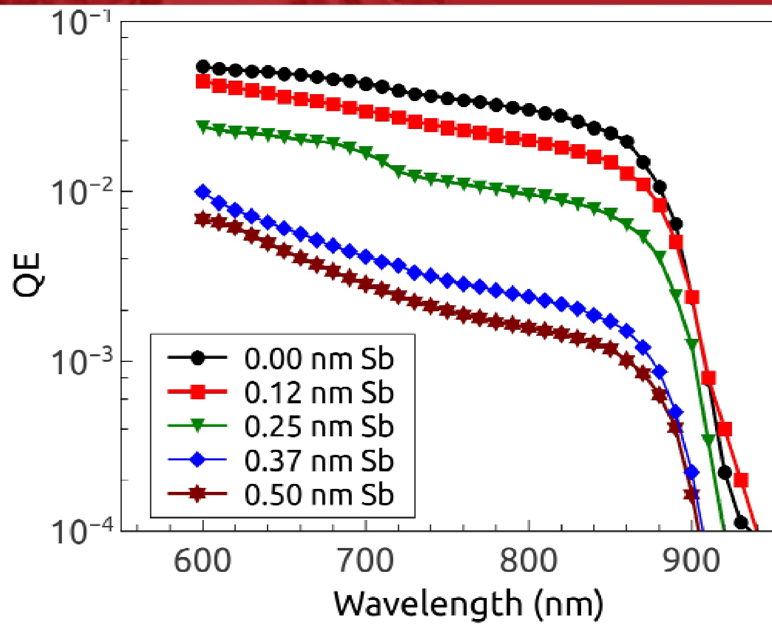
All the methods allowed reaching NEA
co-deposition of Cs-Sb-O_2 allow:

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



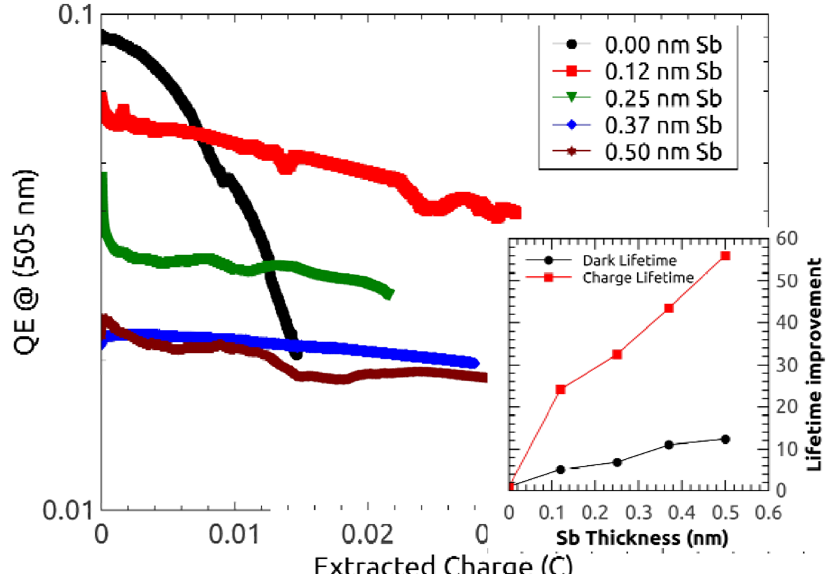
Cs_3Sb on GaAs - Thickness





as we increase the layer thickness:

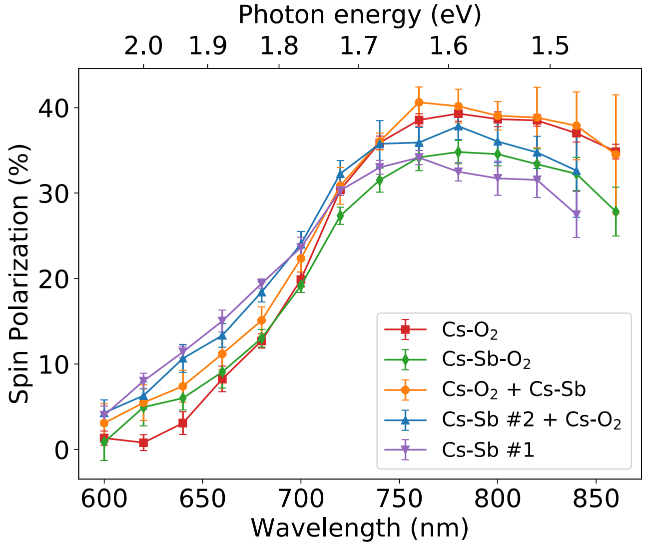
- QE decreases
- Lifetime increases

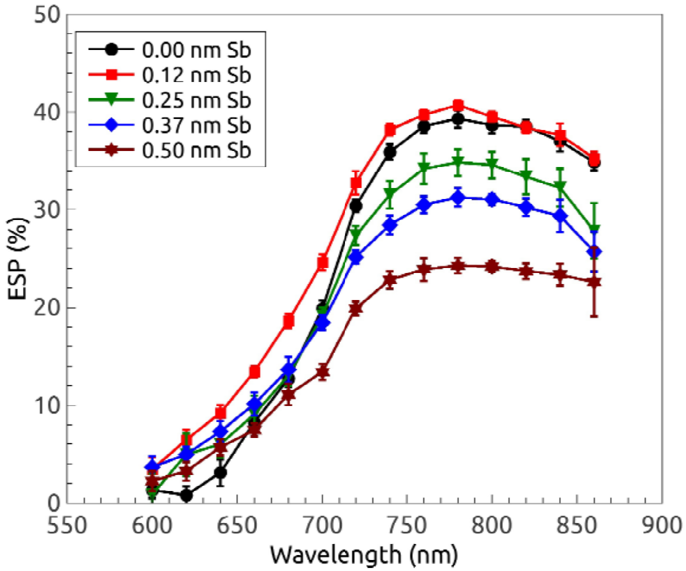


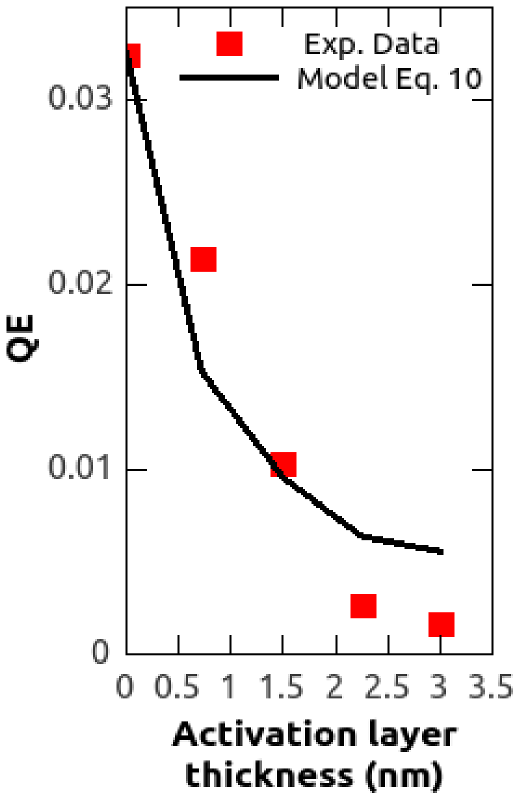
Spin polarization

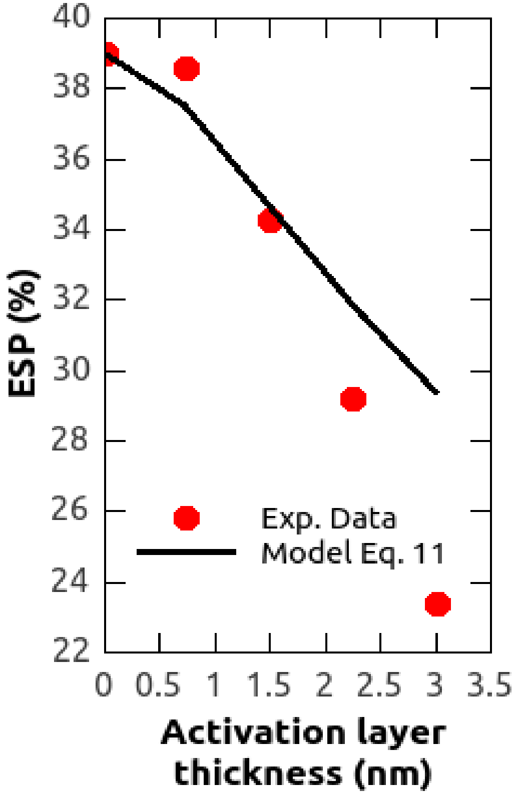
J. Bae et al, NAPAC 2019, MOPLH17

@780 nm









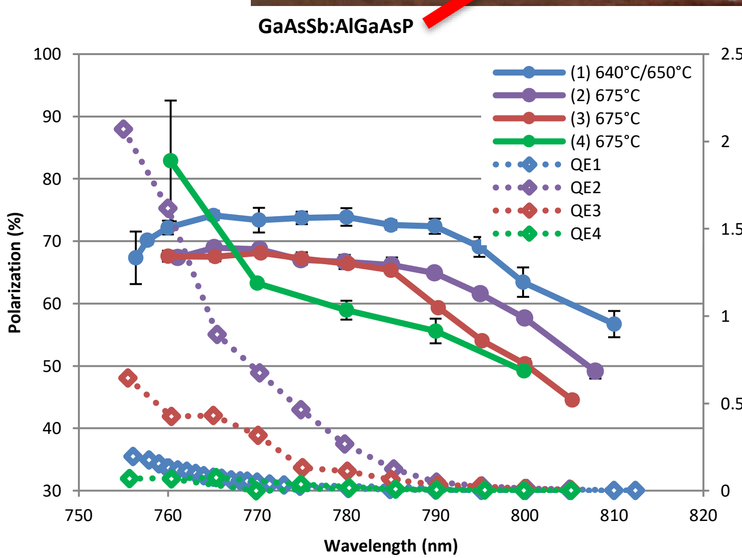
Spin polarization is essentially preserved (up to ~1 nm thickness)

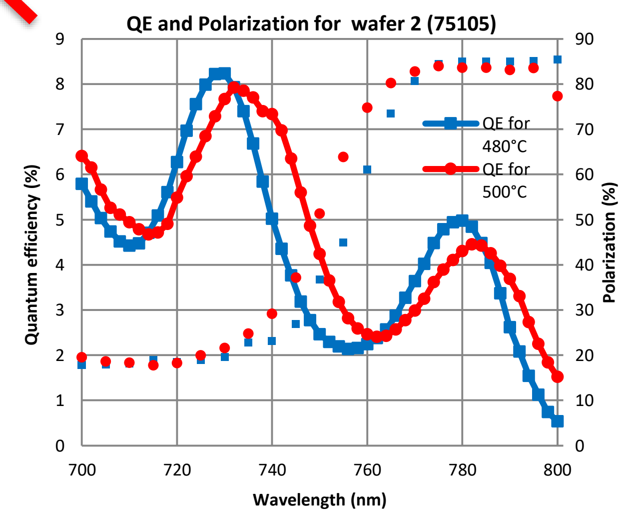
Can all of this be applied from bulk GaAs to high polarization photocathodes?

During 2018 EIC meeting…

- JLab has shown interest in our results:
  - Provided us with 3 super-lattice samples;
  - Interest in test the coating in one of their guns;
  - Measure polarization and lifetime at high energies and high currents;

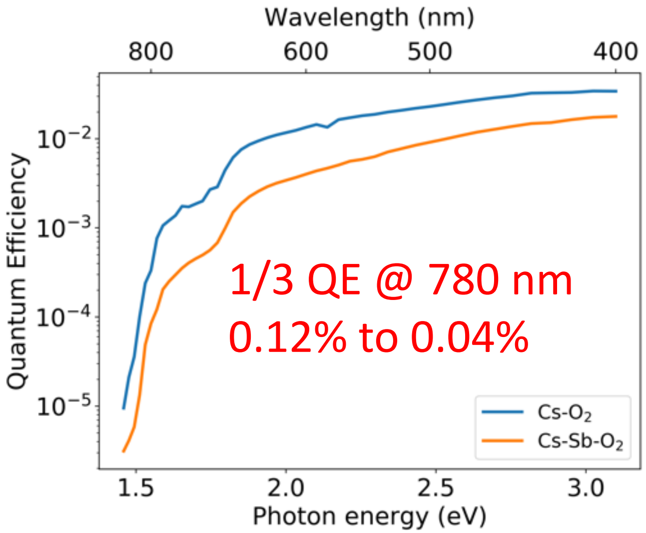
SL with P>80% @780nm

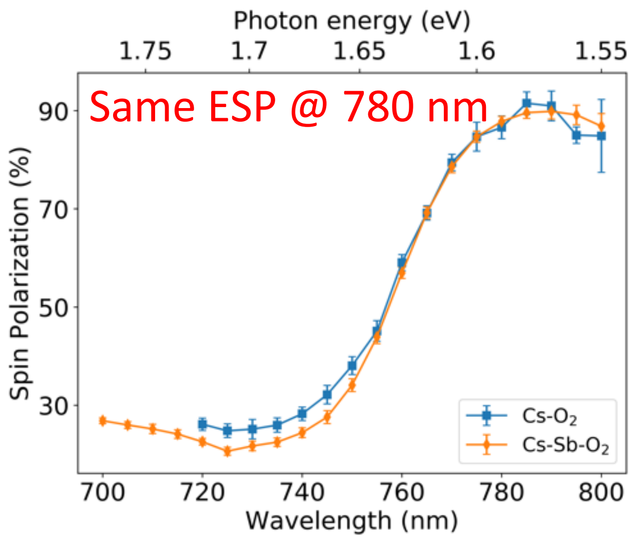


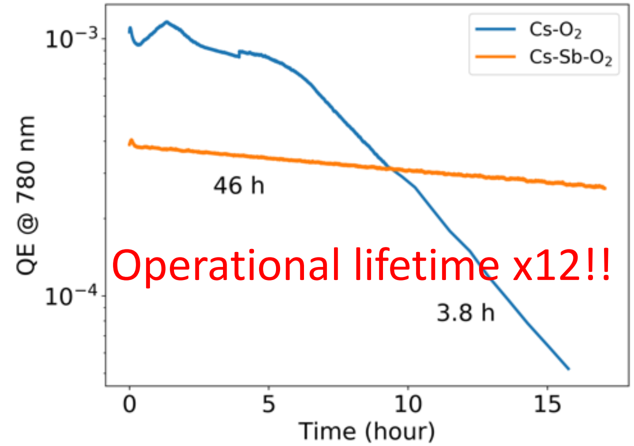


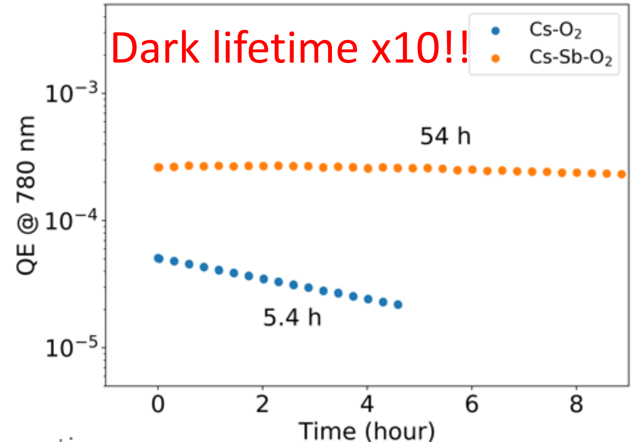
YES!!

SL GaAs/GaAsP non DBR with P>80% @780nm From Jlab injector group

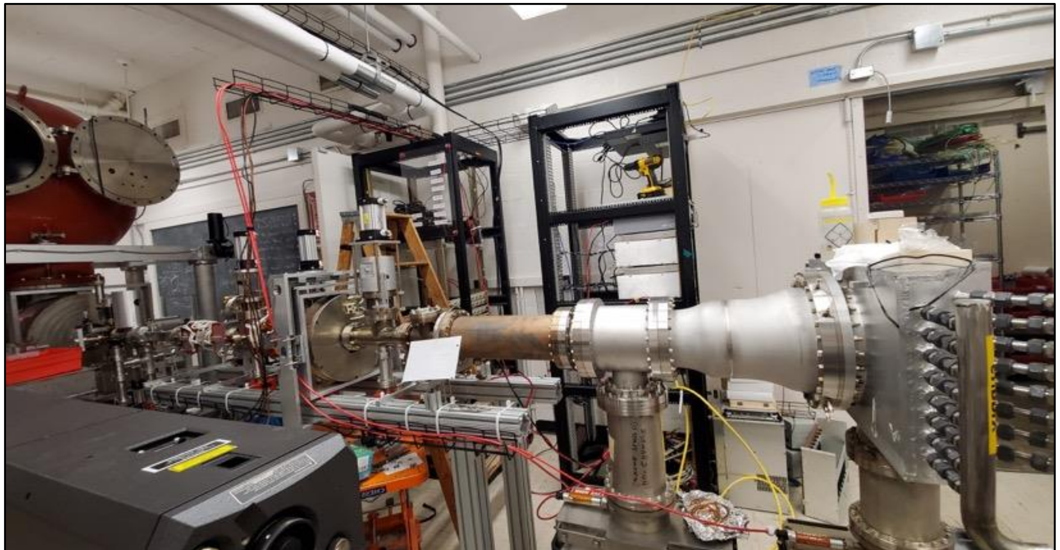


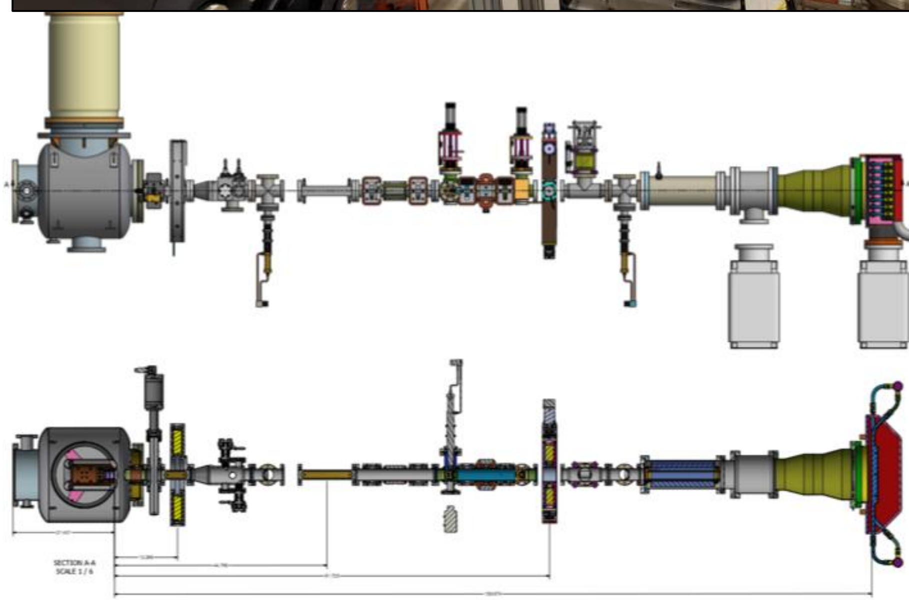






Next?: High power cathode test





Completing the installation of a dedicated beamline:

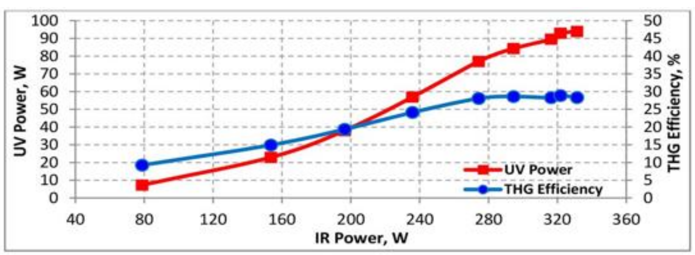
- Old CU-ERL gun 400kV @ 100 mA;
- Ion clearing electrodes;
- High power lasers;
- 75 kW beam dump;

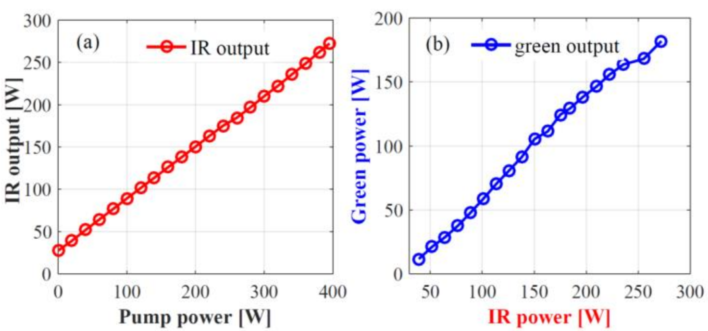
This task has seen some delay in FY2018 due to the simultaneous CHESS-U and CBETA installation

Planned beam tests

- Test the robustness of the GaAs activated with Cs_2Te and Cs_3Sb in the gun at high current;
- Operate alkali antimonides and III-N in the near UV:
  - 343 nm from THG of our pulsed laser system;
  - 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:

https://doi.org/10.1117/12.2185614

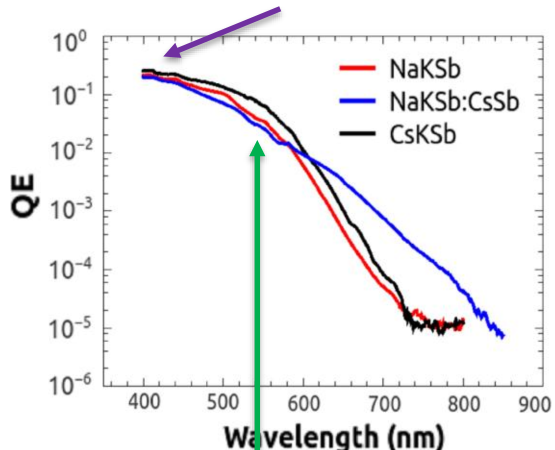




180 W picosecond green laser from a frequency-doubled rod fiber amplifier

Zhi Zhao, * Brian Sheehy, and Michiko Minty
Brookhaven National Laboratory, Upton, New York 11973, USA
*zzhao@bnl.gov

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



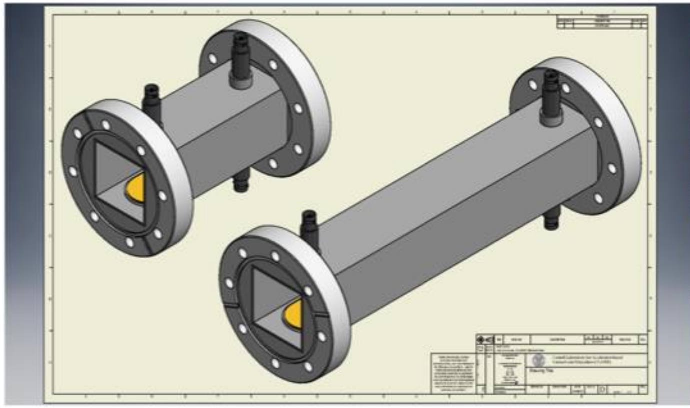
IR to VIS => efficiency 0.6
VIS to e- => efficiency 0.07

IR to e- => ~8%

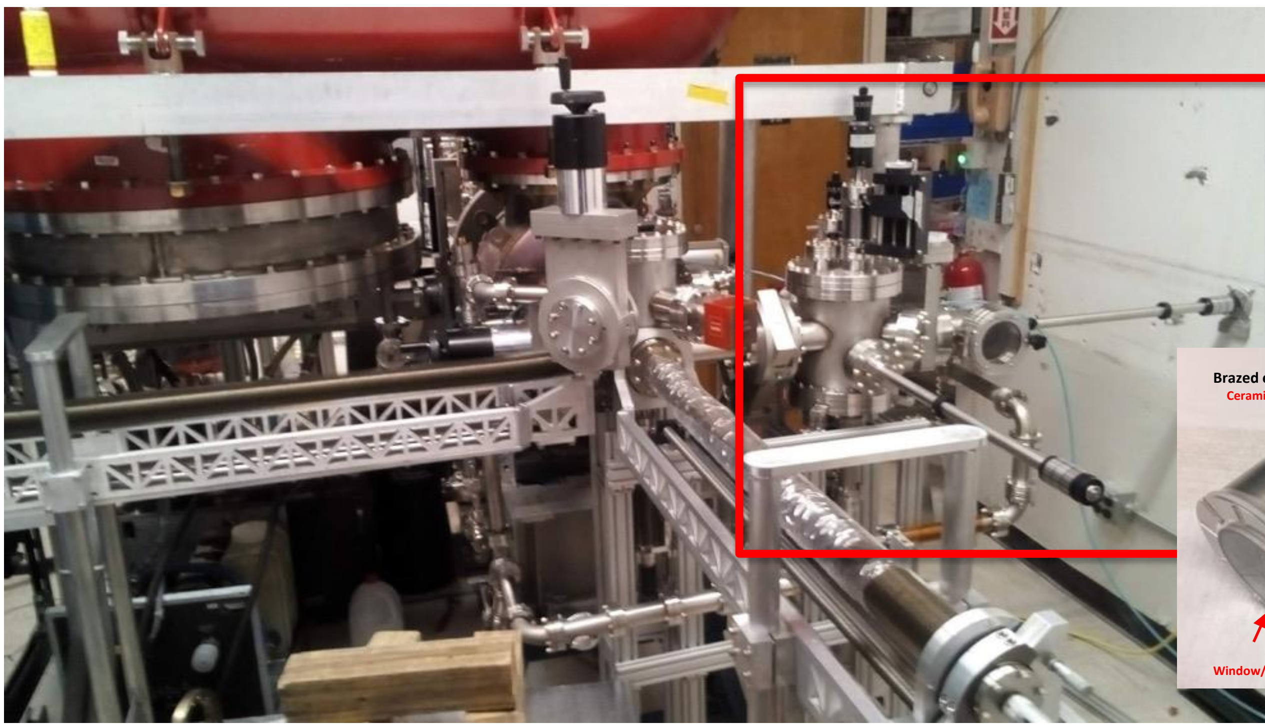
IR to e- => ~4%

- 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%;**

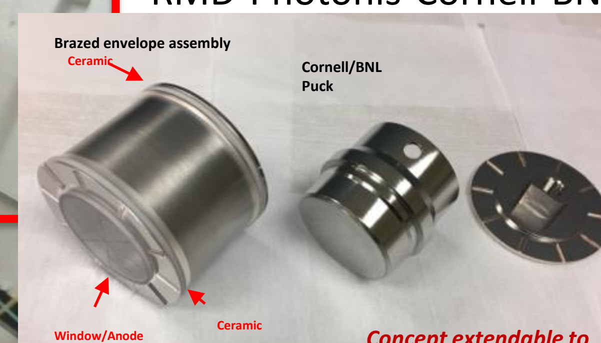
Gun beamline status



- Gun+Beamline+loadlock are installed and in UHV;
- Clearing electrodes are installed;
- Load-lock includes a “cathode-in-canister” delivery system (SBIR-Phase II);

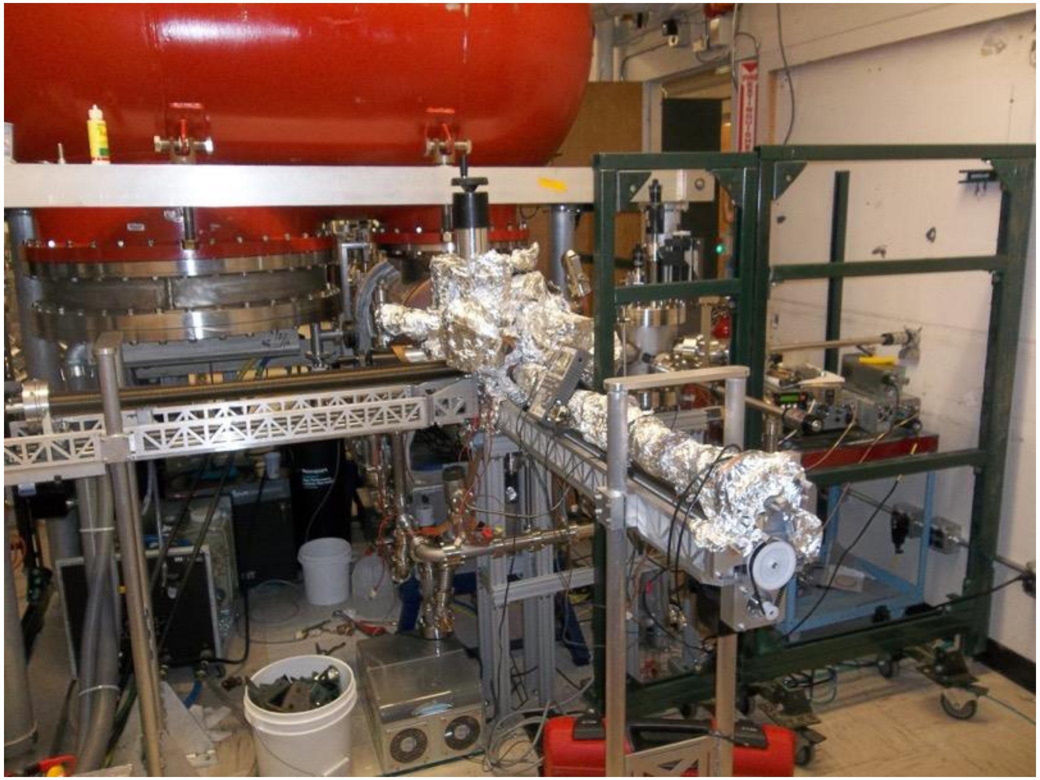


RMD-Photonis-Cornell-BNL



Concept extendable to other plug design

Just a little more effort…



- *Completing lead shielding installation;*
- *PPS Checkout;*
- *SF6 emergency venting line;*

- ***Turn on HV!!***

Thank you for the attention!!

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NP-DOE DE-SC0019122

and collaborators:

Ivan Bazarov (PI),
Jai Kwan Bae (graduate student),

And the photocathode development group at CLASSE