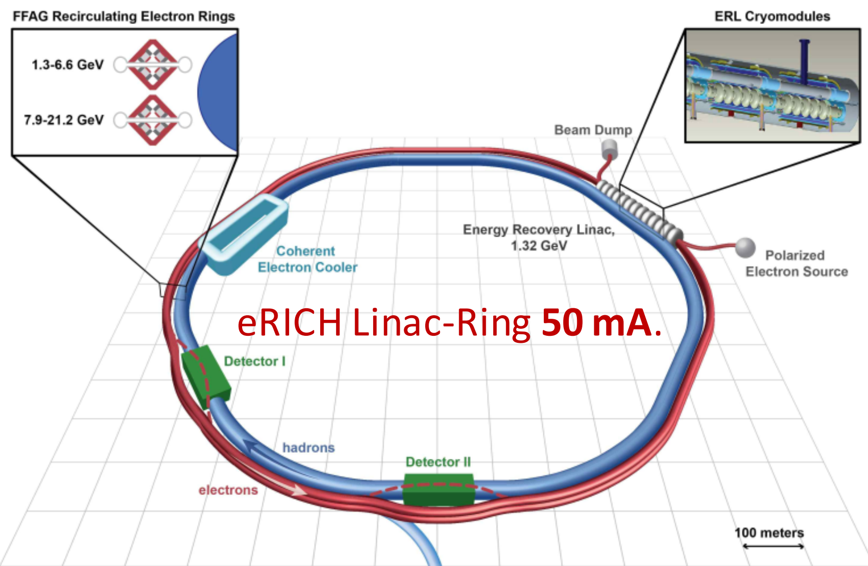
High current polarized electron sources development

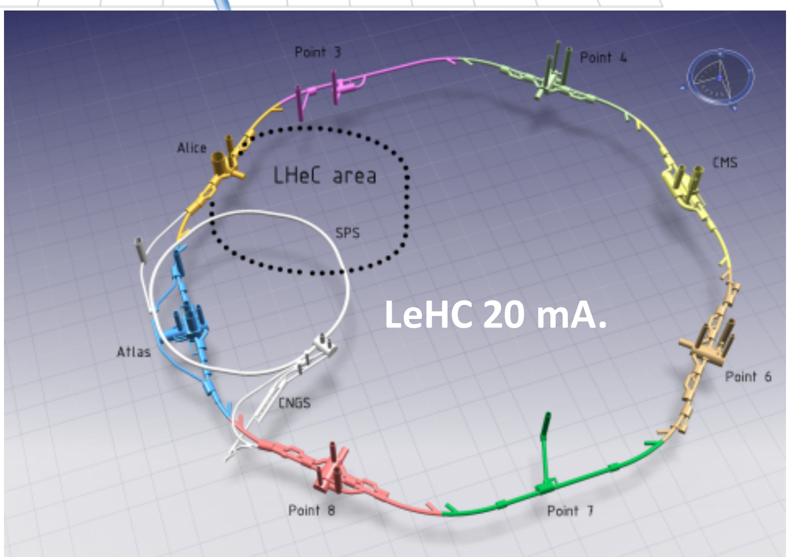
Luca Cultrera

Outline

- Spin polarized photocathode requirements;
- State-of-the-art of GaAs-based photocathodes;
- Photoemission R&D at Cornell University;
- Cs_2Te and Cs_3Sb activated GaAs;
- Outlook and future work;

High current and spin polarization



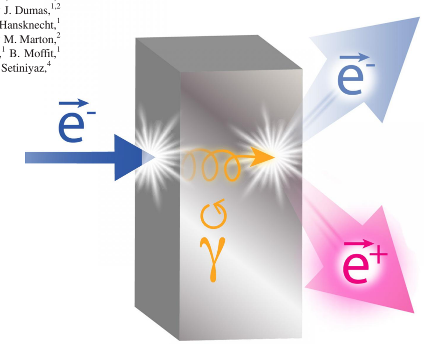


PRL **116,** 214801 (2016) PHYSICAL REVIEW LETTERS week ending 27 MAY 2016

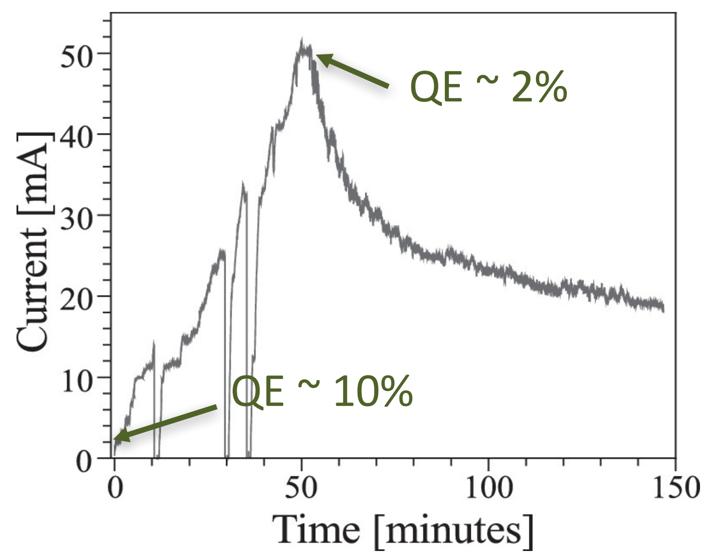
Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies

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



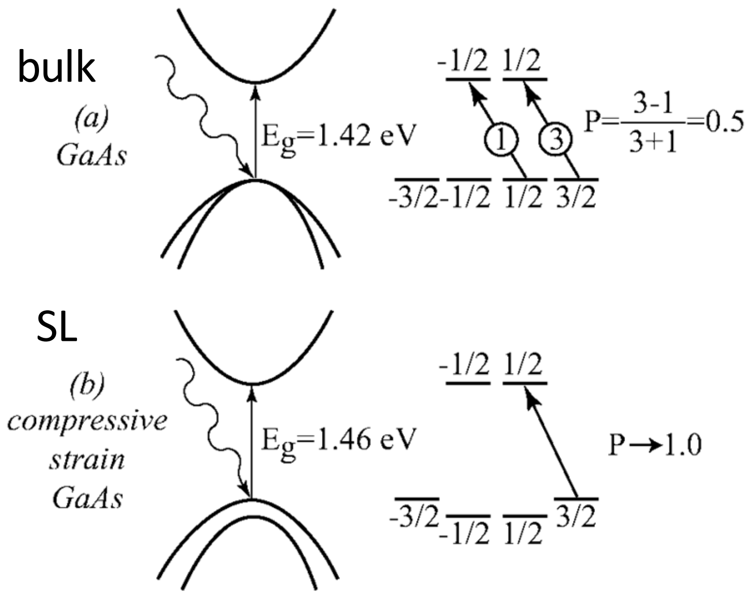
GaAs @ 532 nm (~5 Watts)
200 Coulomb



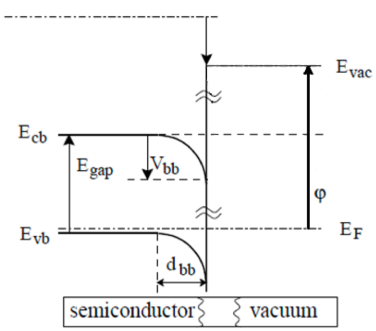
B. Dunham et al, Appl. Phys. Lett. **102**, 034105 (2013)

GaAs-based existing photocathodes

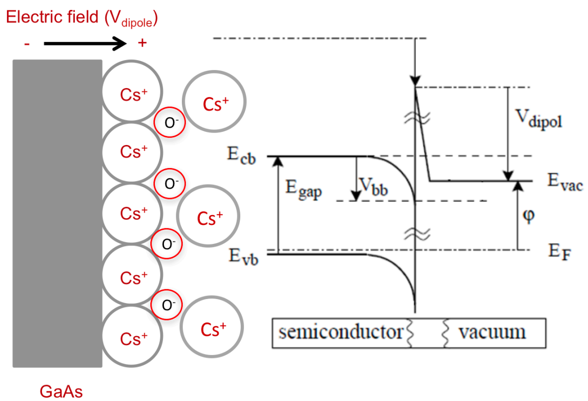
At **typical 1% QE** the required laser power "on the cathode" @800 nm to generate **50 mA** is about **7 Watts**



Before Activation



After Activation (NEA)



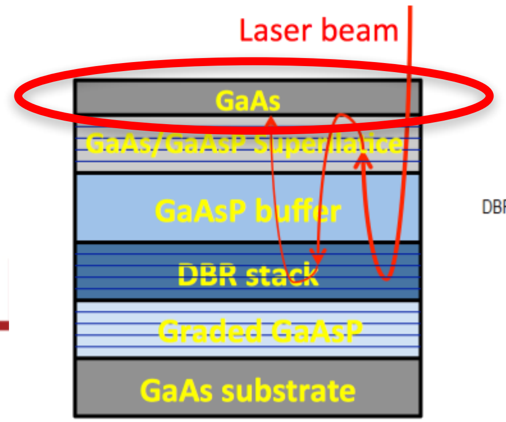
All GaAs based photocathodes requires Cs-O activation to achieve Negative Electron Affinity (NEA) and vacuum levels better than 10^{-11} Torr to survive a few days (without even running the beam)

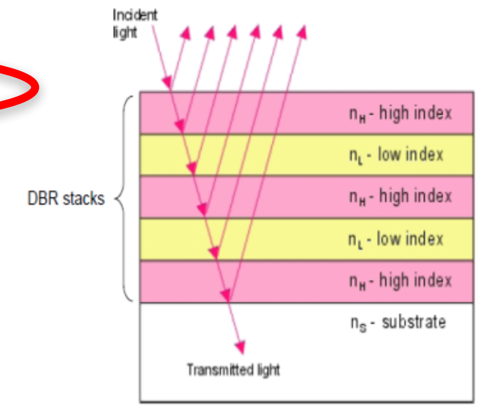
Distributed Bragg Reflector

- *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

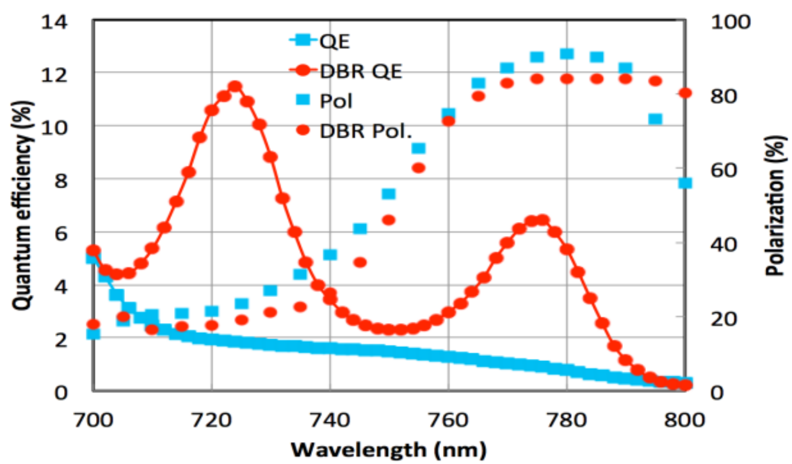




S. ZHANG, P3 Workshop 2016, Newport News, VA — Jefferson Lab

Experimental Results

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



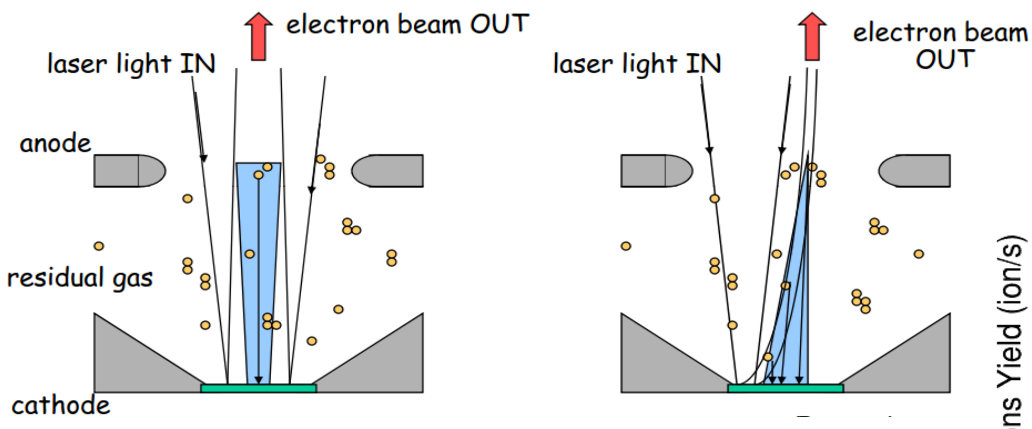
S. ZHANG, P3 Workshop 2016, Newport News, VA — Jefferson Lab

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

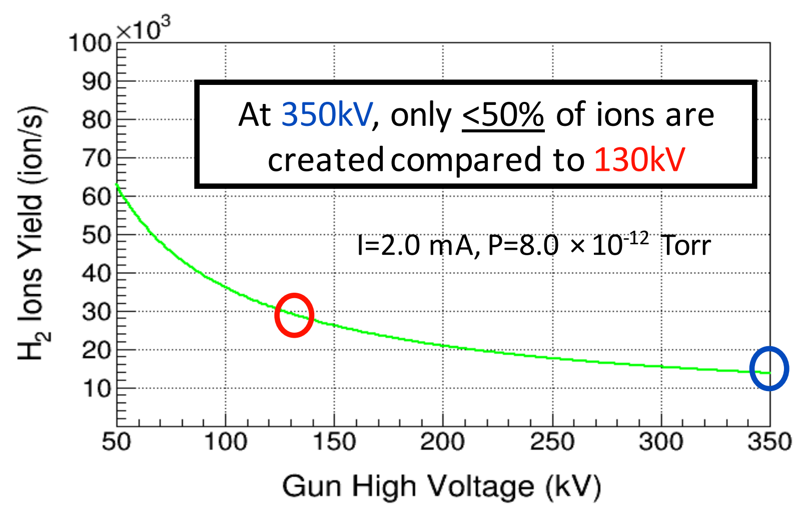
THE LAST LAYER IS A HIGHLY P-DOPED BULK GaAs ACTIVATED WITH Cs-O

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;



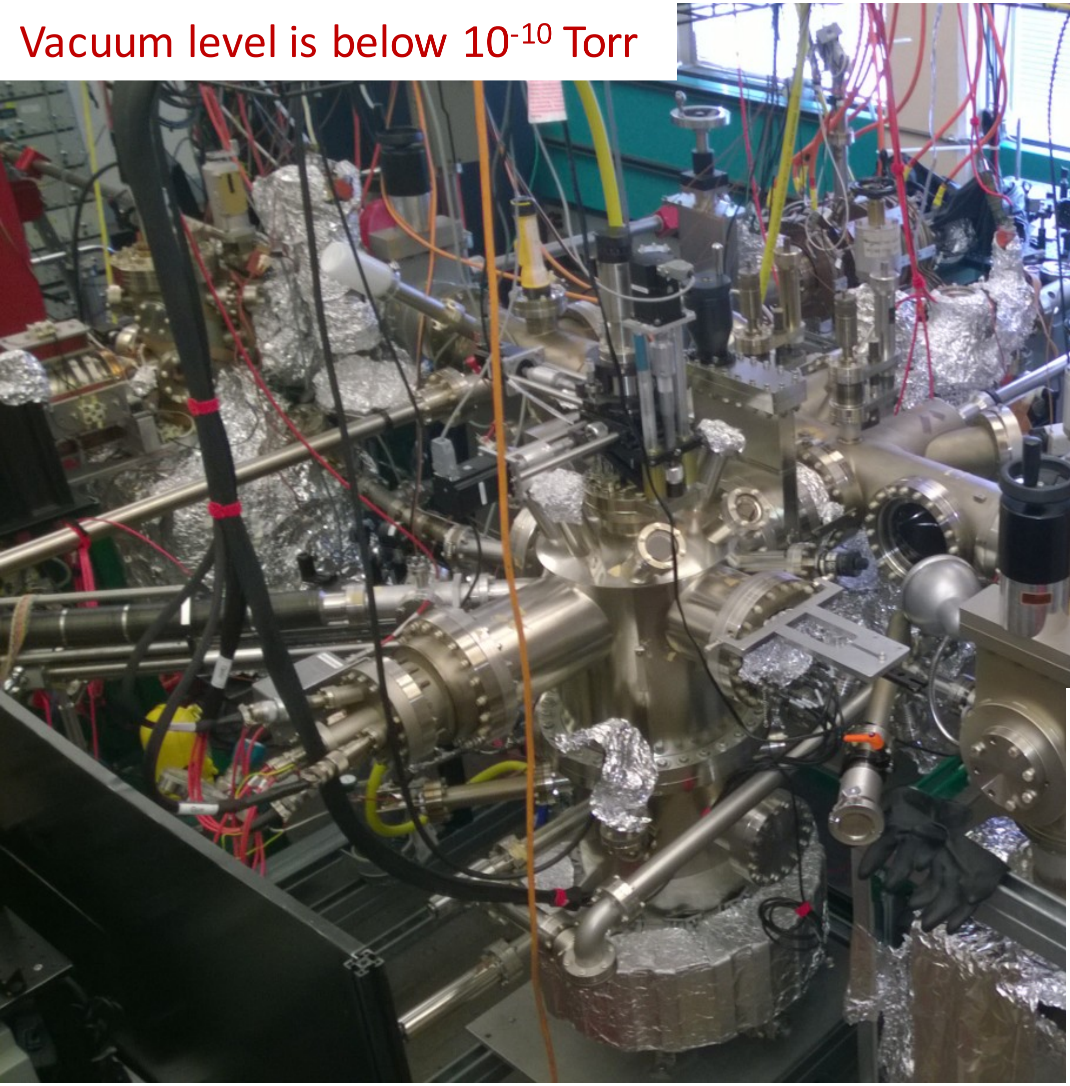
A single HV breakdown event inside the gun Can get the vacuum high enough to instantly "kill" the cathode

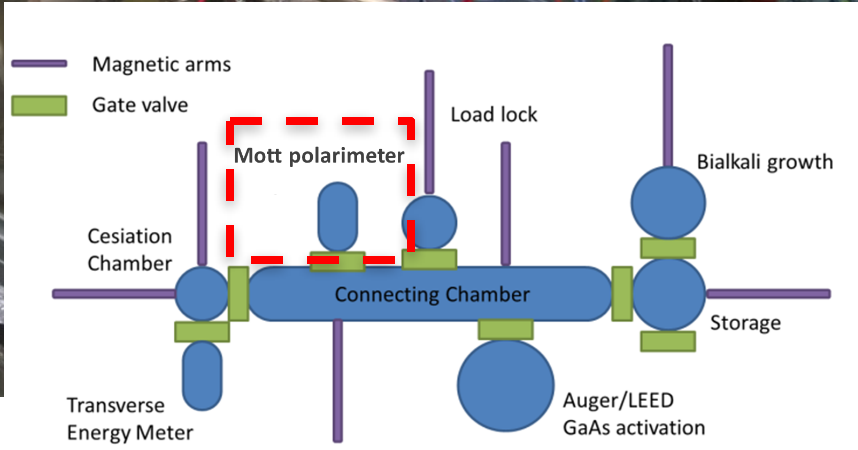


Courtesy of J. Grames

Cornell Photocathode Lab

Vacuum level is below 10^{-10} Torr

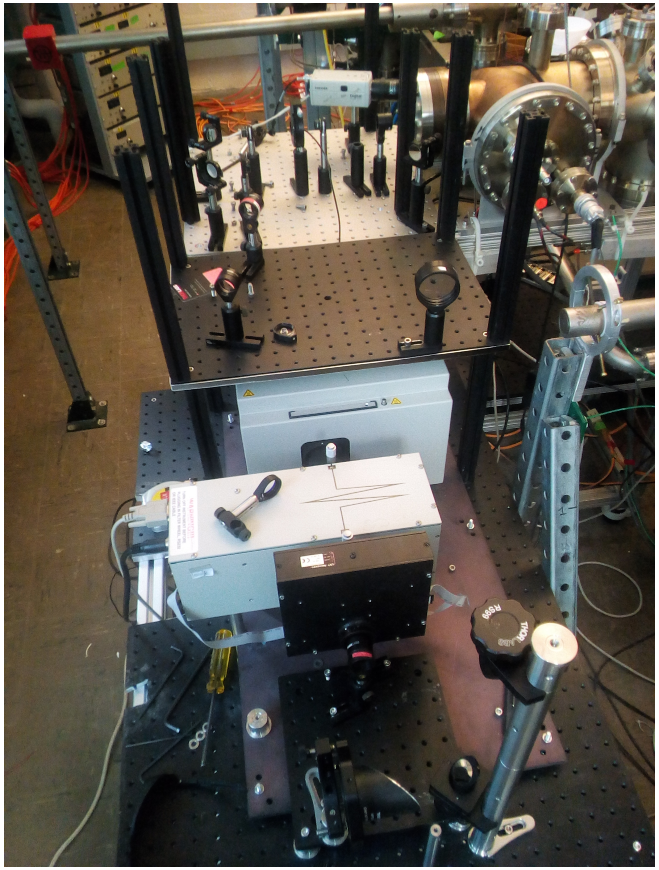


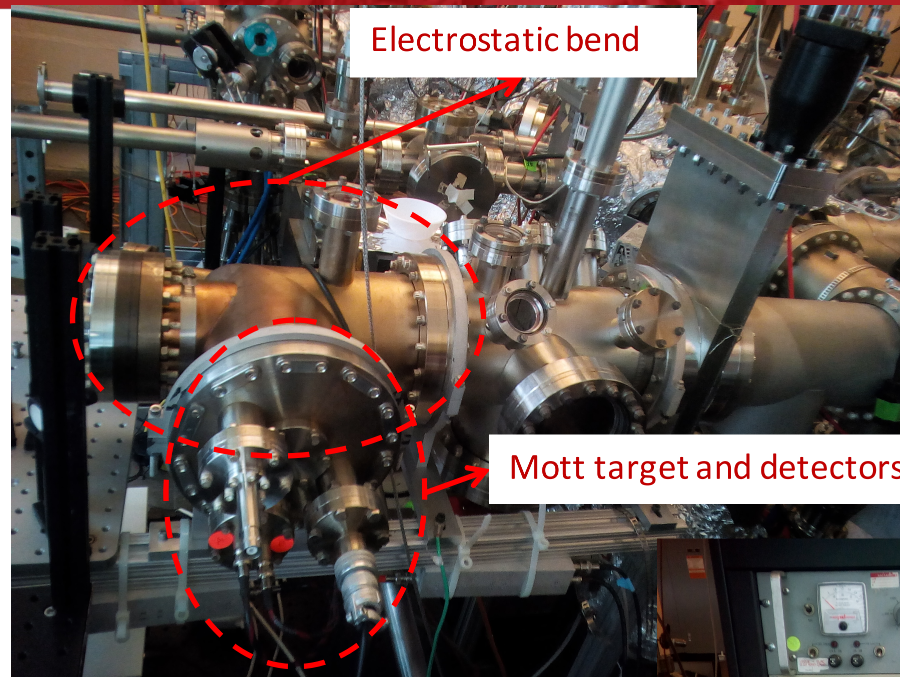


Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Mott polarimeter @ CU

Vacuum level is below 10^{-10} Torr





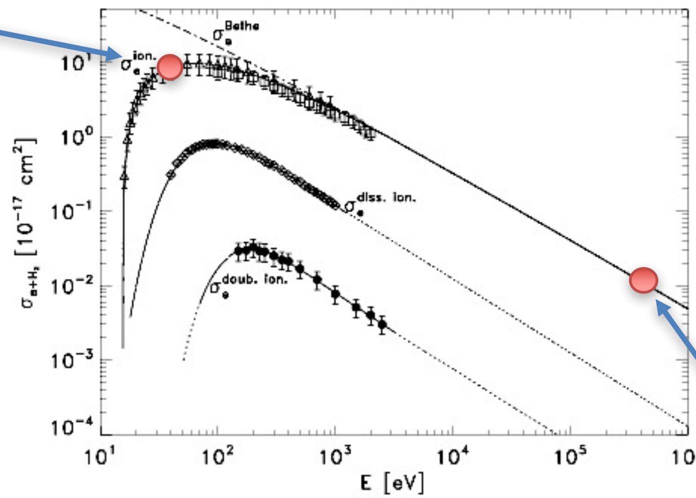
The retarding field Mott polarimeter has been refurbished upgraded and fully integrated into the photocathode lab UHV installation.

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

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;

Beam energy in our setup is about 36 eV

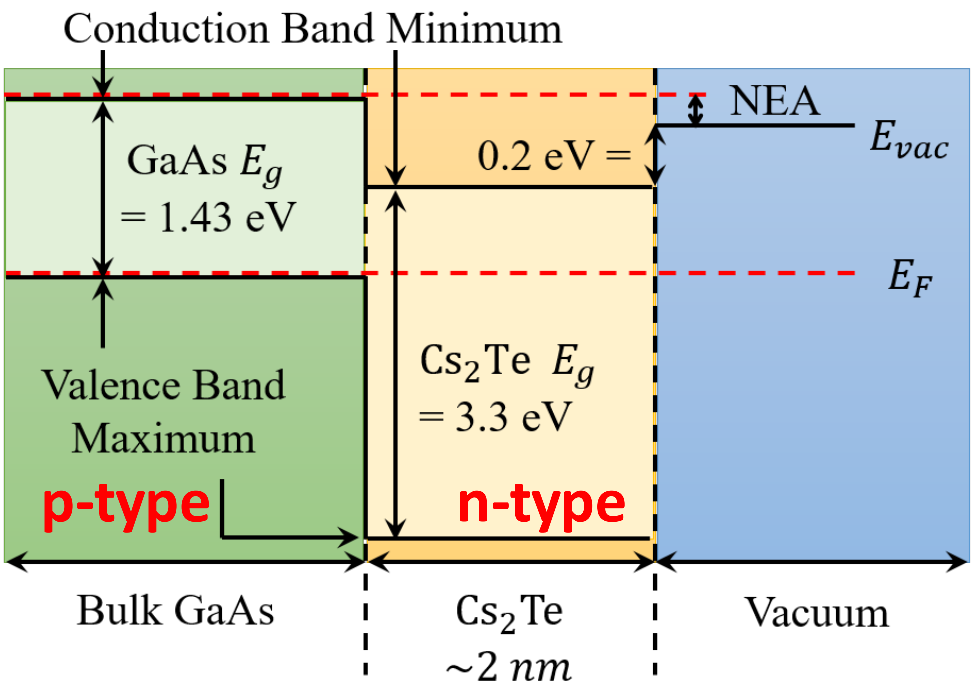


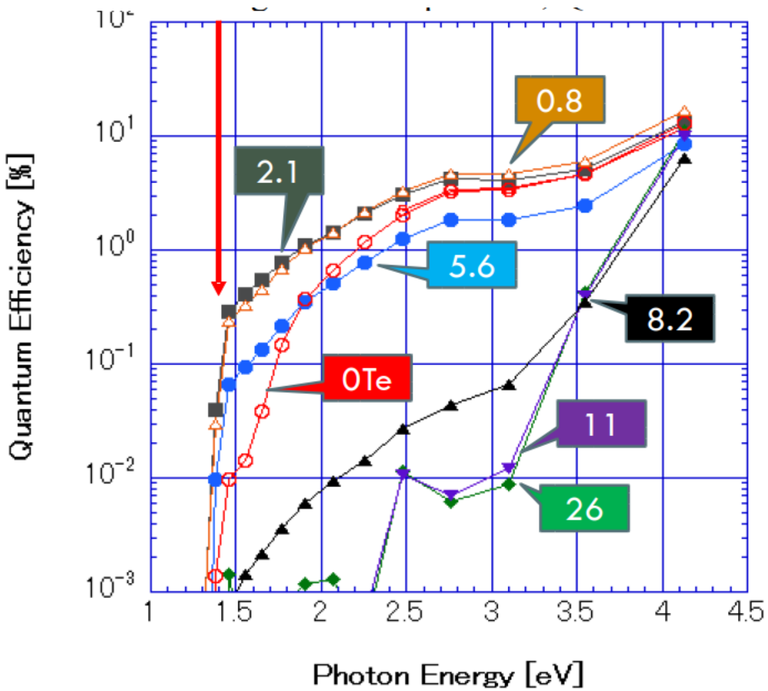
Beam energy in CU gun

- 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

M. Kuriki, P3 workshop, LBNL, 2014

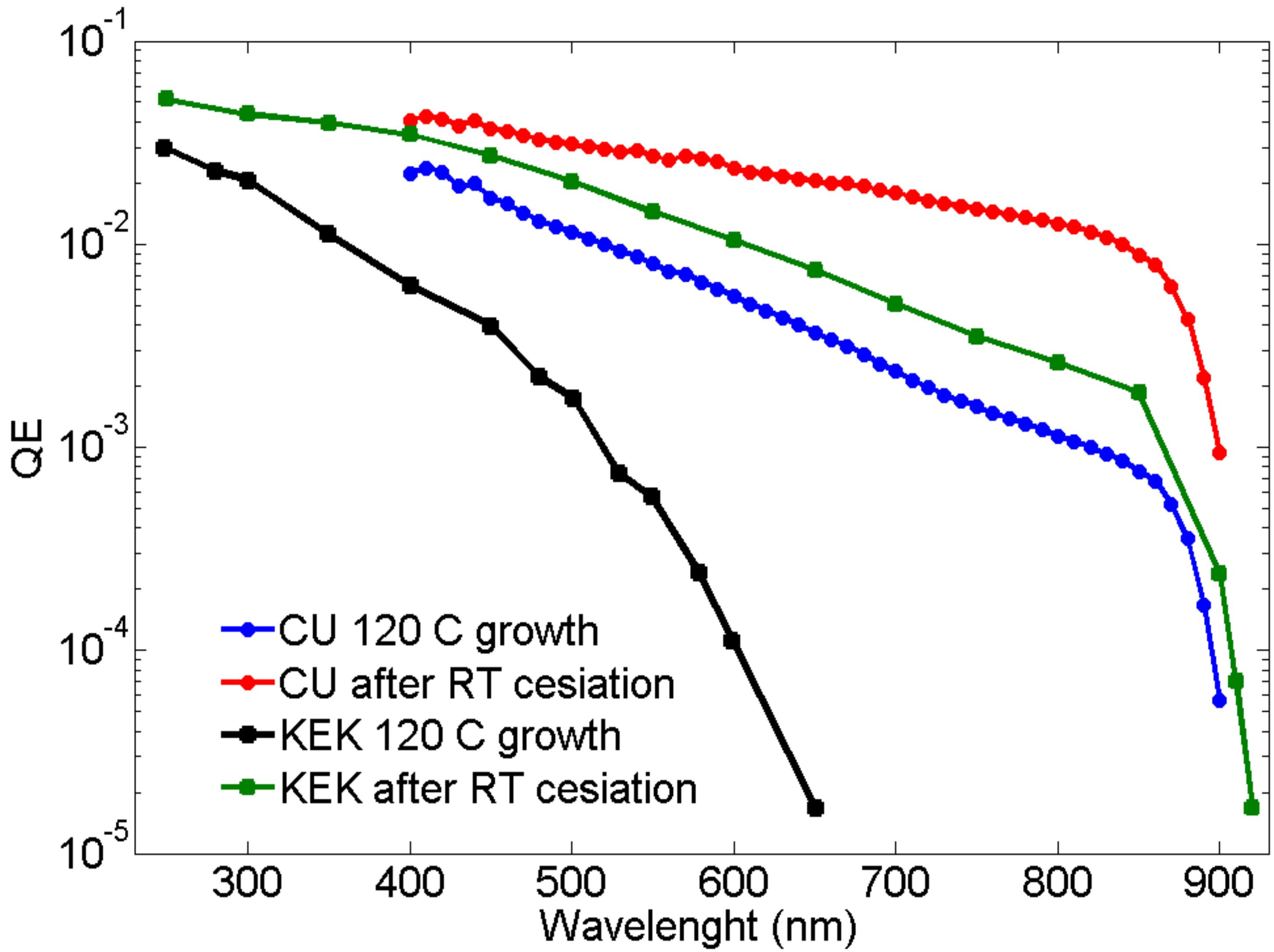




Will this method yield longer lifetimes?

What happen to the spin polarization?

NEA with Cs_2Te on bulk GaAs



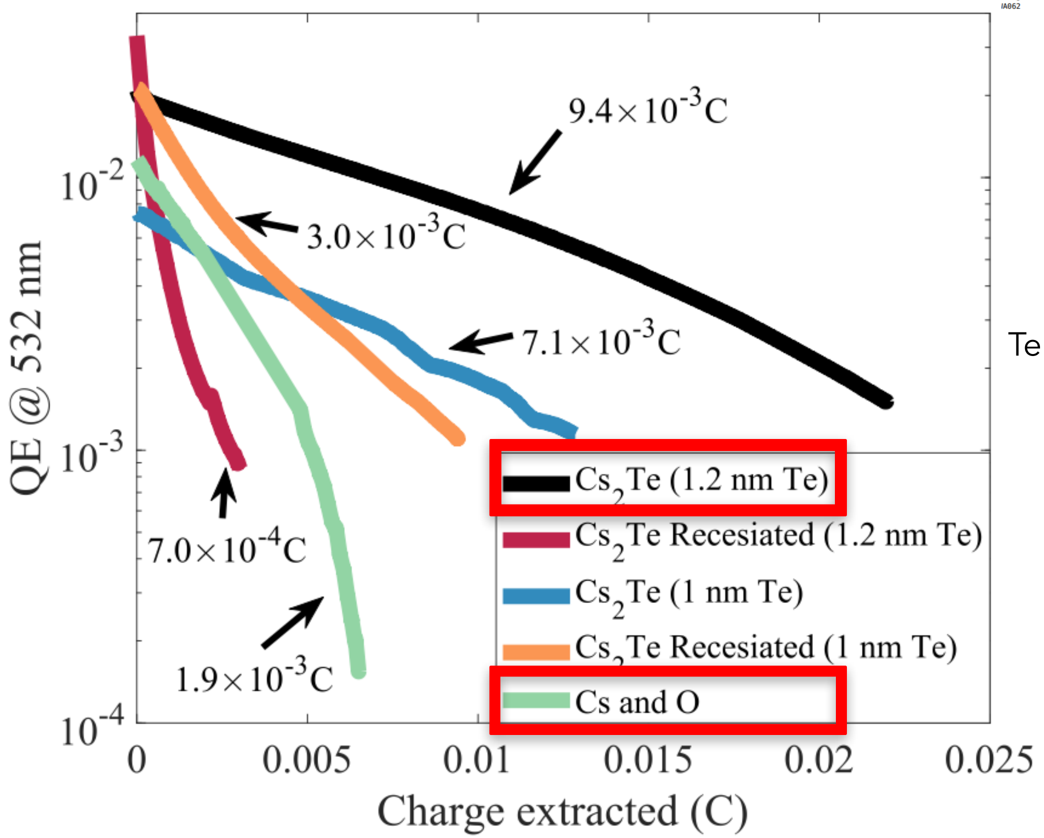
J. Bae et al., Appl. Phys. Lett. ***112*** *(2018) 154101*

Cs_2Te and CsKTe on GaAs

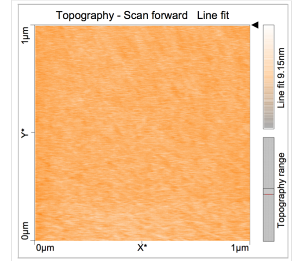
O. Rahman et al., IPAC 2019, TUPTS102

5X LIFETIME!

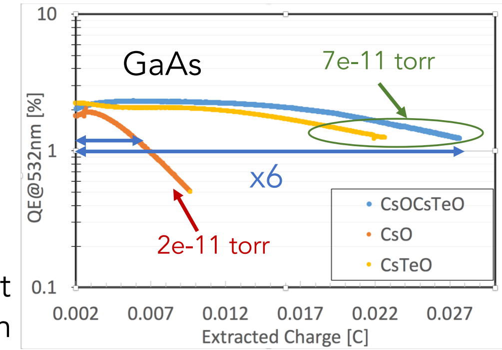
@532 nm



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



540 °C heat treatment
Roughness:1.8-3.9 nm



Te source in Saes dispenser

Trying GaAs/GaAsP and CsI coating now.

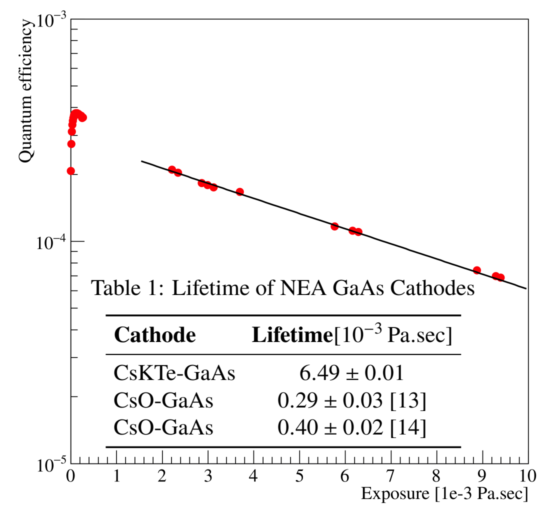


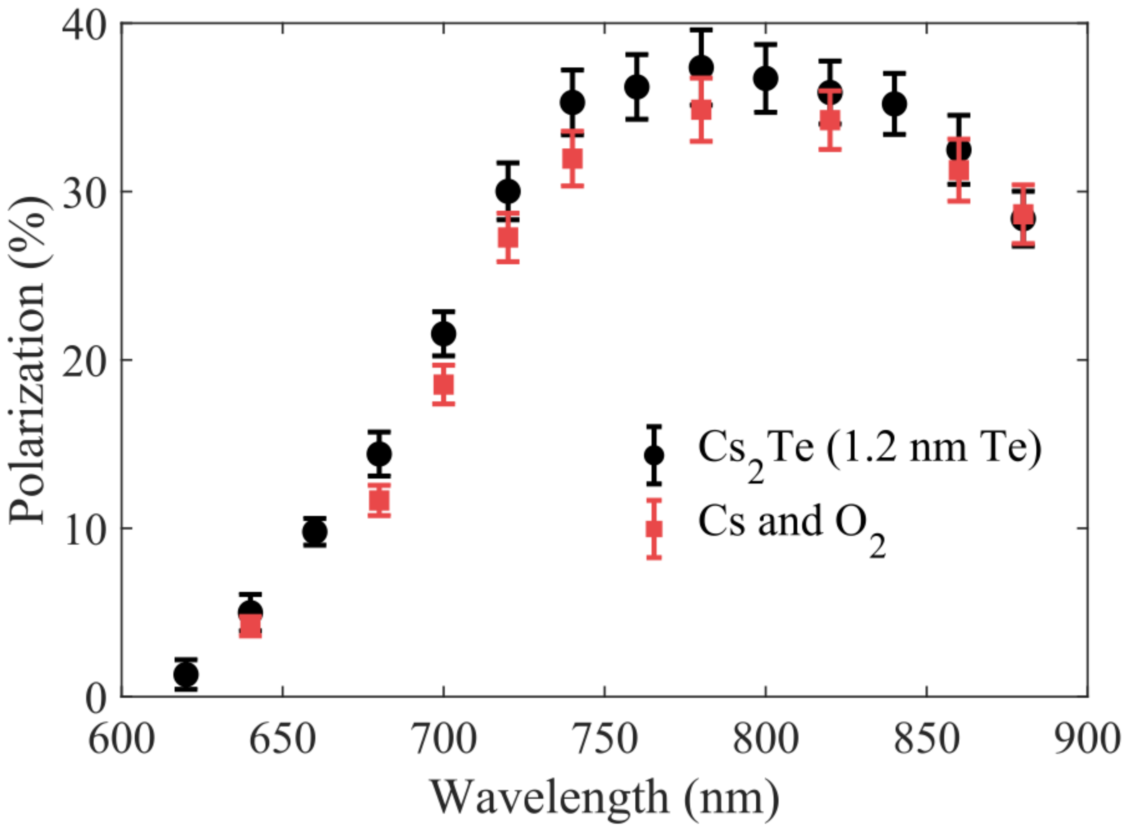
Table 1: Lifetime of NEA GaAs Cathodes

Cathode	Lifetime[10^{-3} Pa.sec]
CsKTe-GaAs	6.49 ± 0.01
CsO-GaAs	0.29 ± 0.03 [13]
CsO-GaAs	0.40 ± 0.02 [14]

M. Kuriki et al., IPAC 2019, TUPTS026

Electron beam polarization

The same GaAs wafer 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

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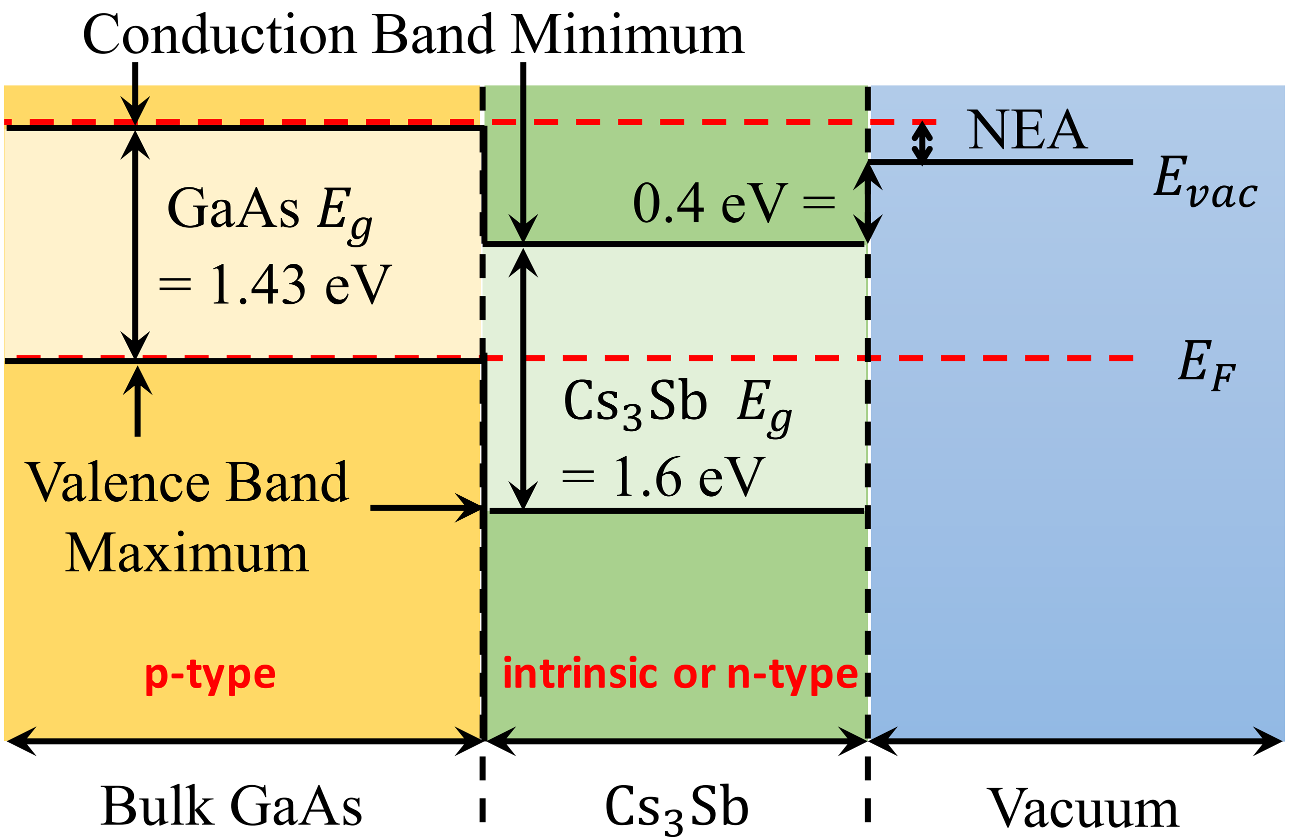
Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University, Ithaca, New York 14853, USA

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

Cs_3Sb on GaAs

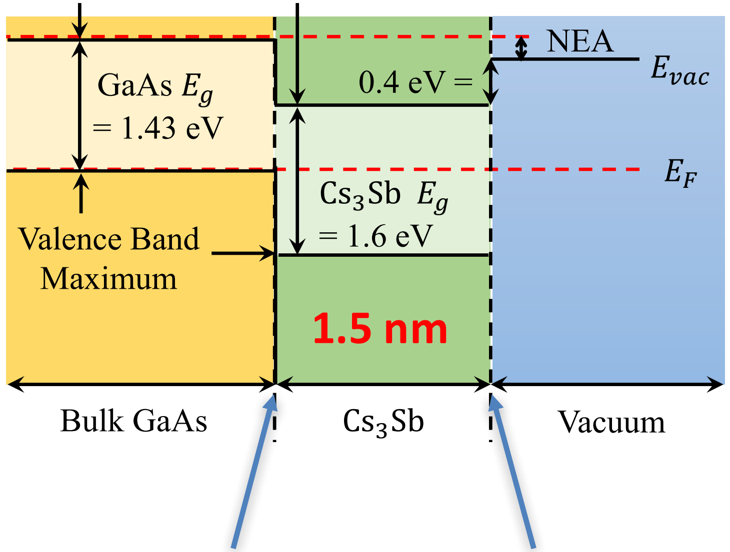
Doping control in alkali based photocathodes materials is difficult

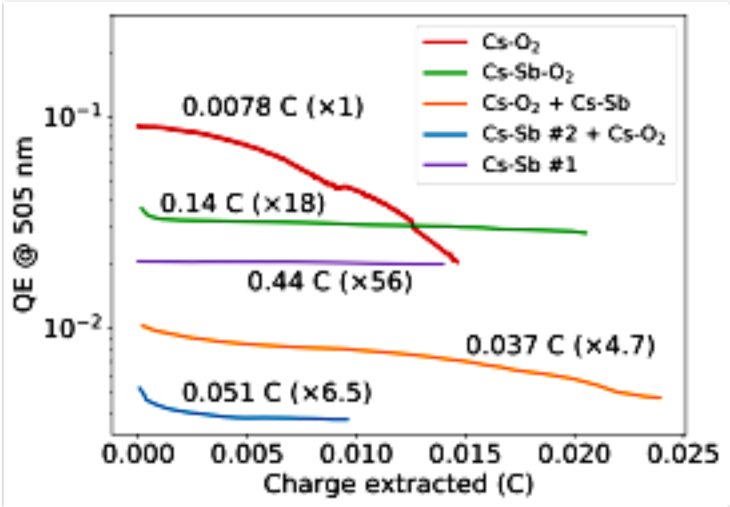


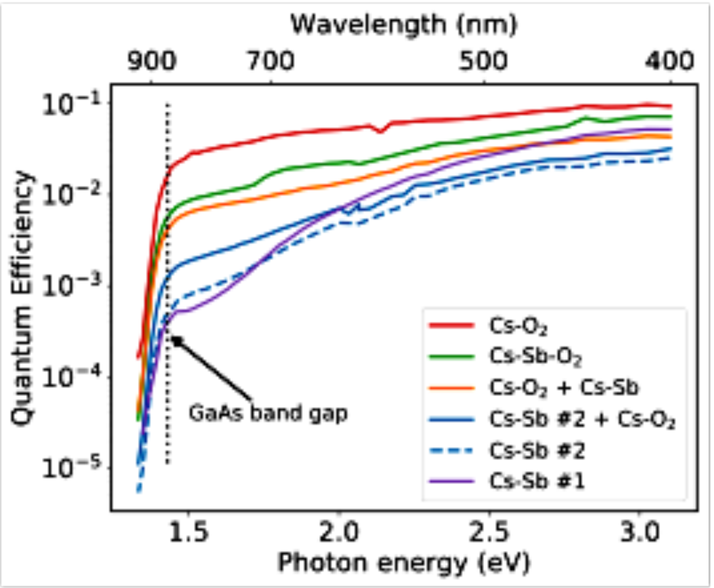
Doping character is controlled by the stoichiometry

Cs_3Sb on GaAs - Methods

J. Bae et al, NAPAC 2019, MOPLH17



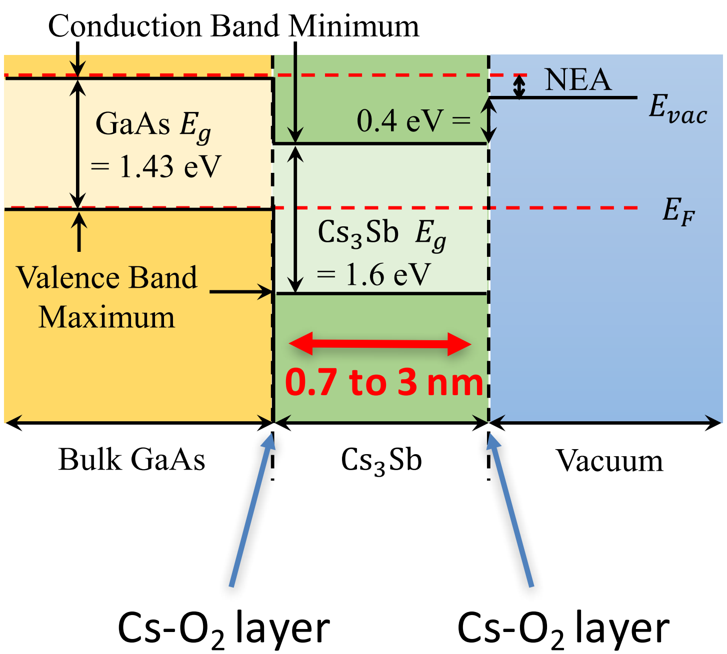


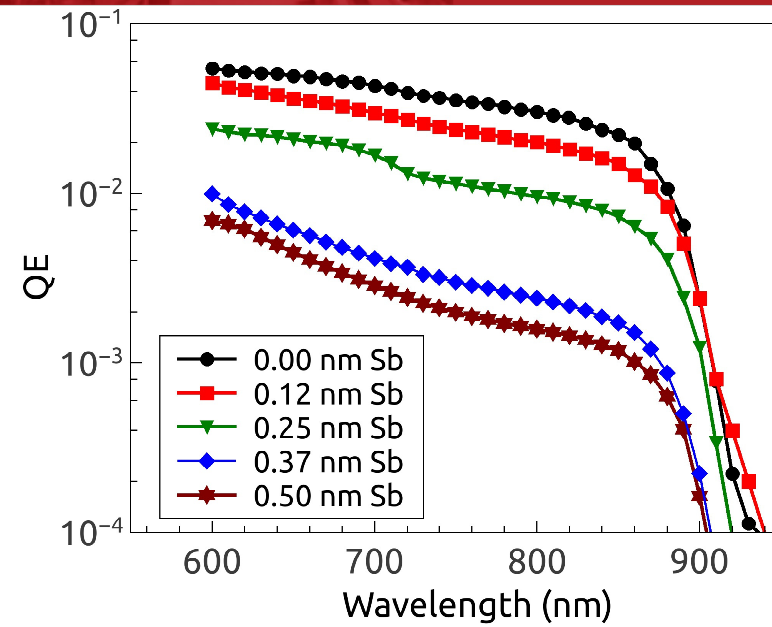


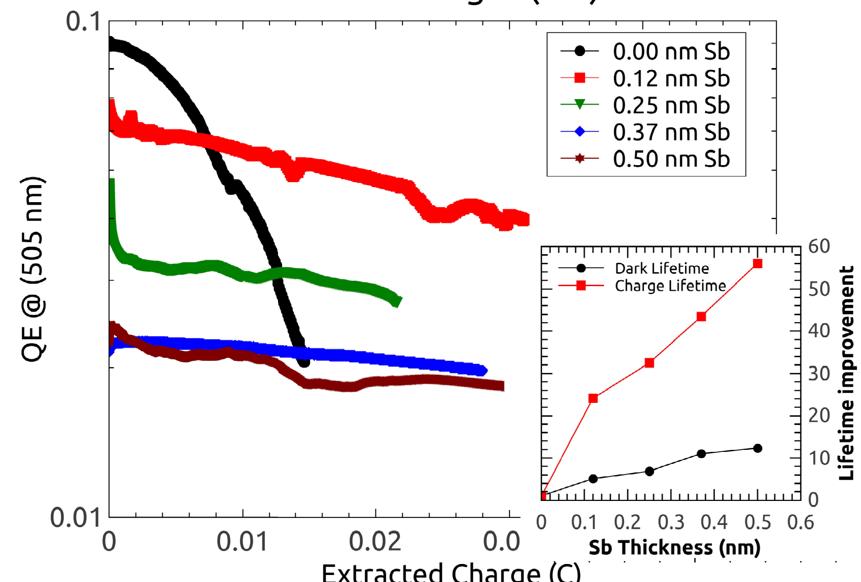
All the methods allowed reaching NEA co-deposition of Cs-Sb-O_2 allow:

- **the longer lifetimes (x20)**
- **and the higher QE (1/2 of Cs-O)**

Cs_3Sb on GaAs - Thickness





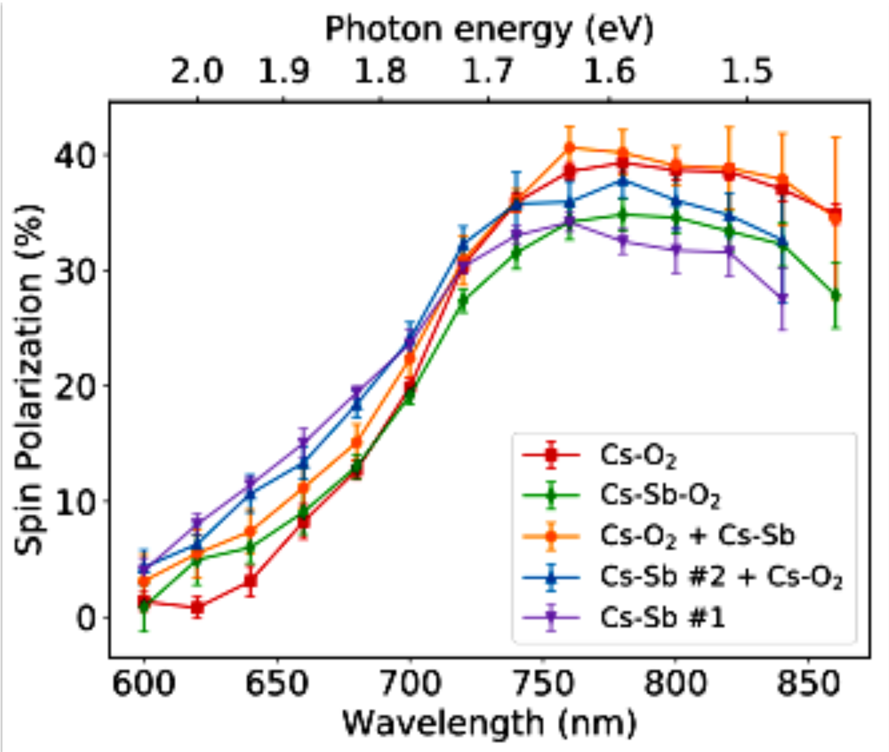


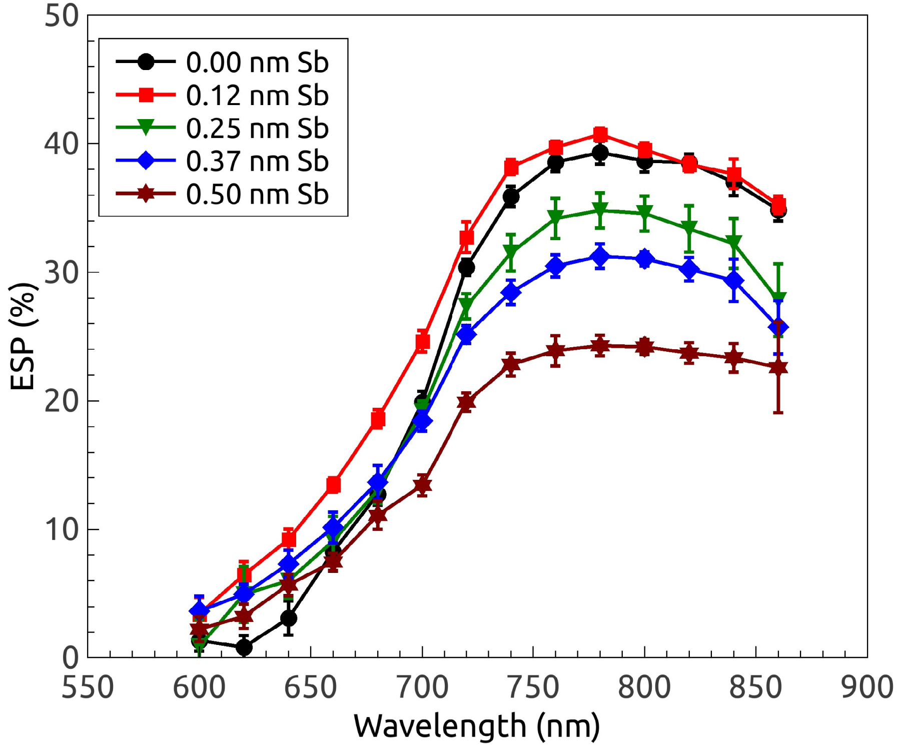
as we increase the layer thickness:

- **QE decreases**
- **Lifetime increases**

Spin polarization

J. Bae et al, NAPAC 2019, MOPLH17





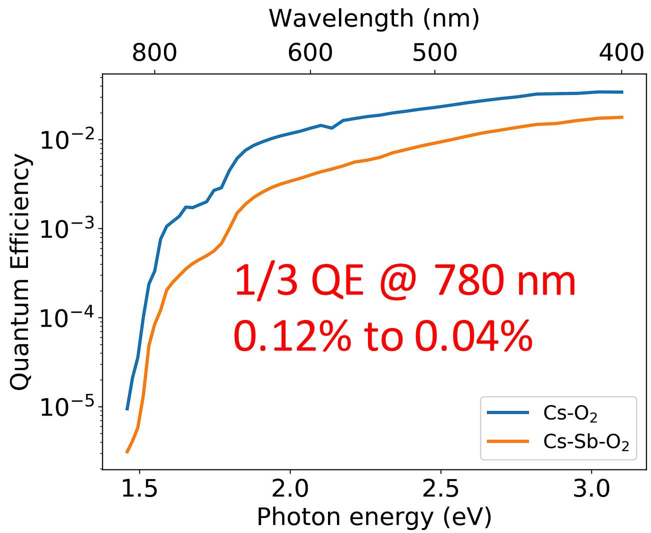
Spin polarization is essentially preserved (up to 1 nm thickness)

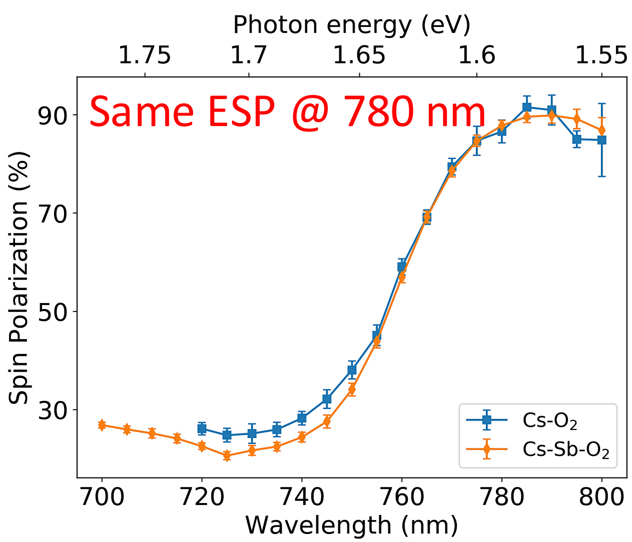
Can all of this be applied from bulk GaAs to high polarization photocathodes?

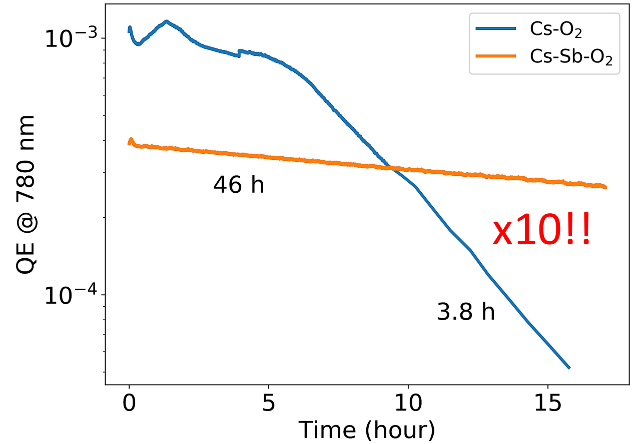
YES!!

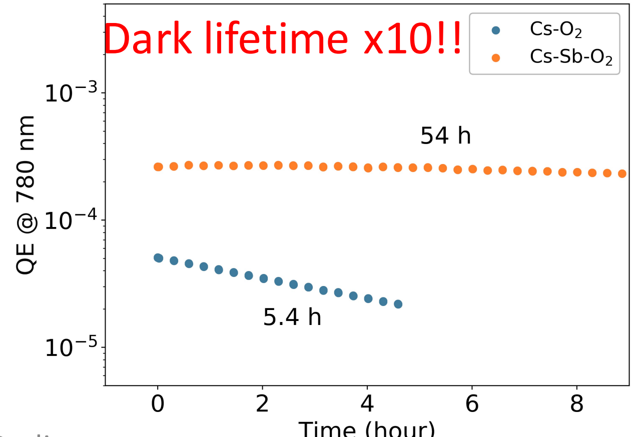
- Preliminary results!

SL GaAs/GaAsP non DBR with P>80% @780nm From Jlab injector group Activated with 0.12 nm Sb

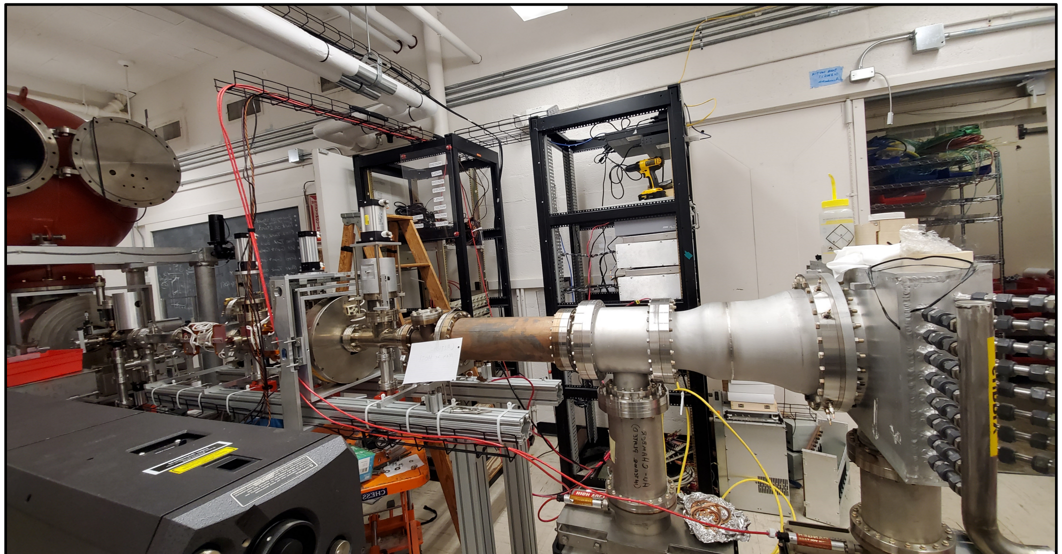


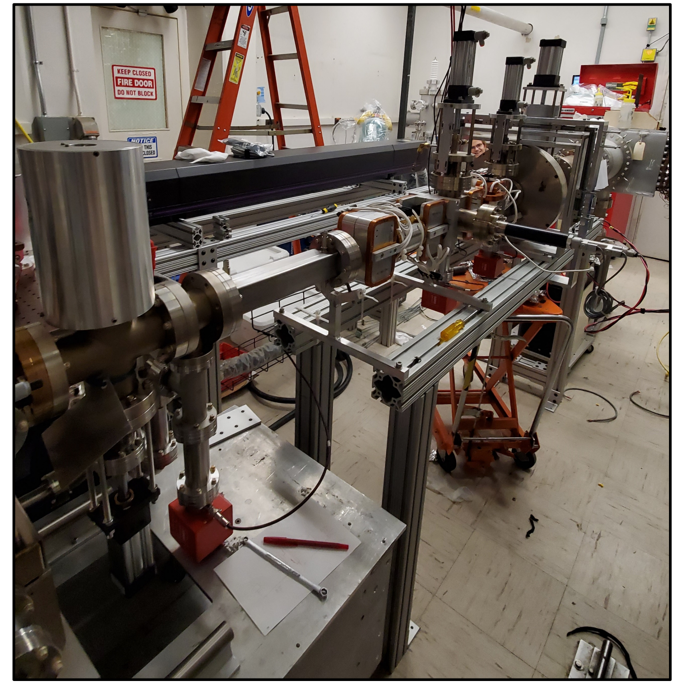


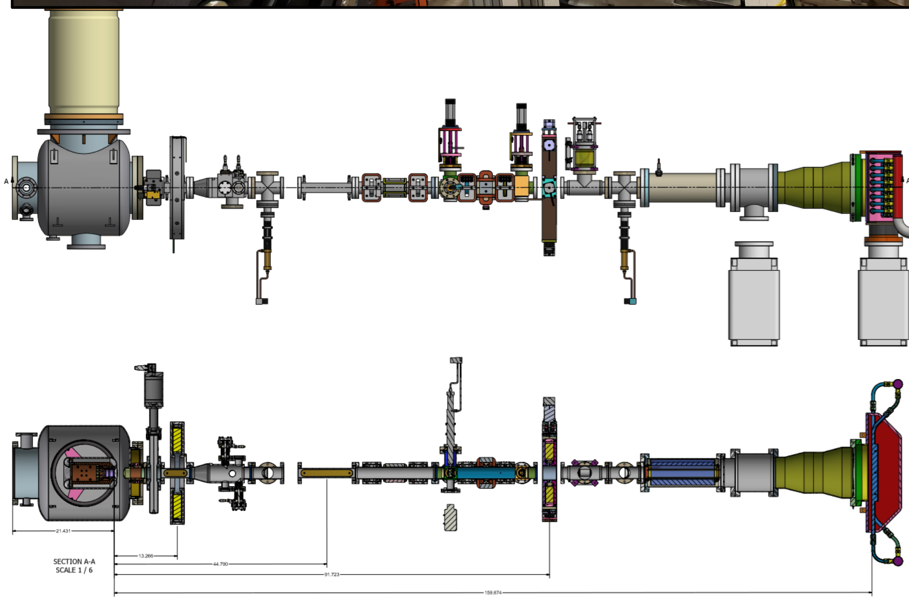




Next?: High power cathode test





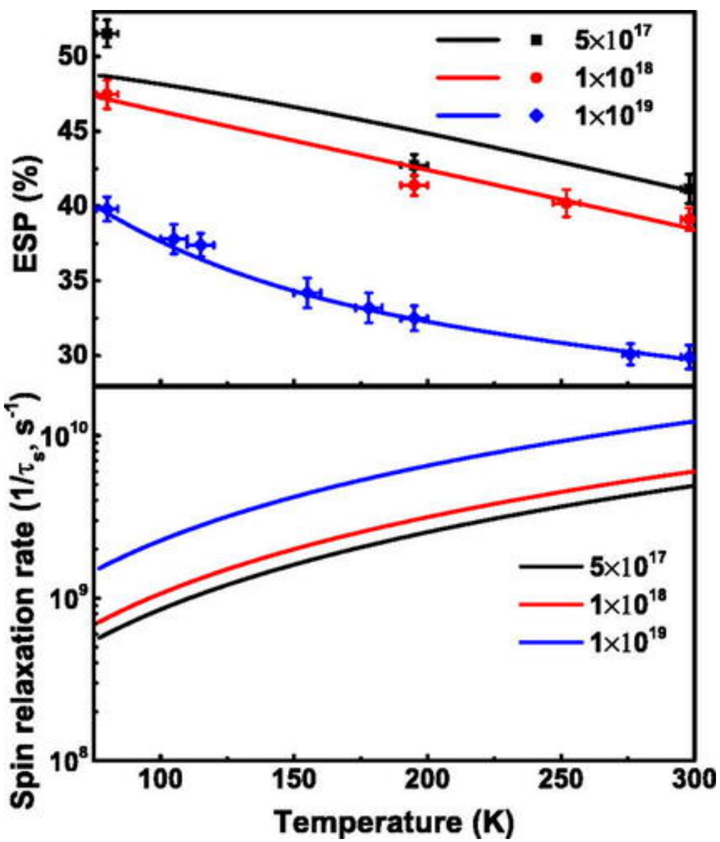


We are completing the installation of a dedicated beamline:

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

Future outlook

ESP can be increased at low temperatures



JOURNAL OF APPLIED PHYSICS 122, 035703 (2017)

A comprehensive evaluation of factors that influence the spin polarization of electrons emitted from bulk GaAs photocathodes

Wei Liu,[1,2,3] Matt Poelker,[3] Xincun Peng,[3,4] Shukui Zhang,[3] and Marcy Stutzman[3]
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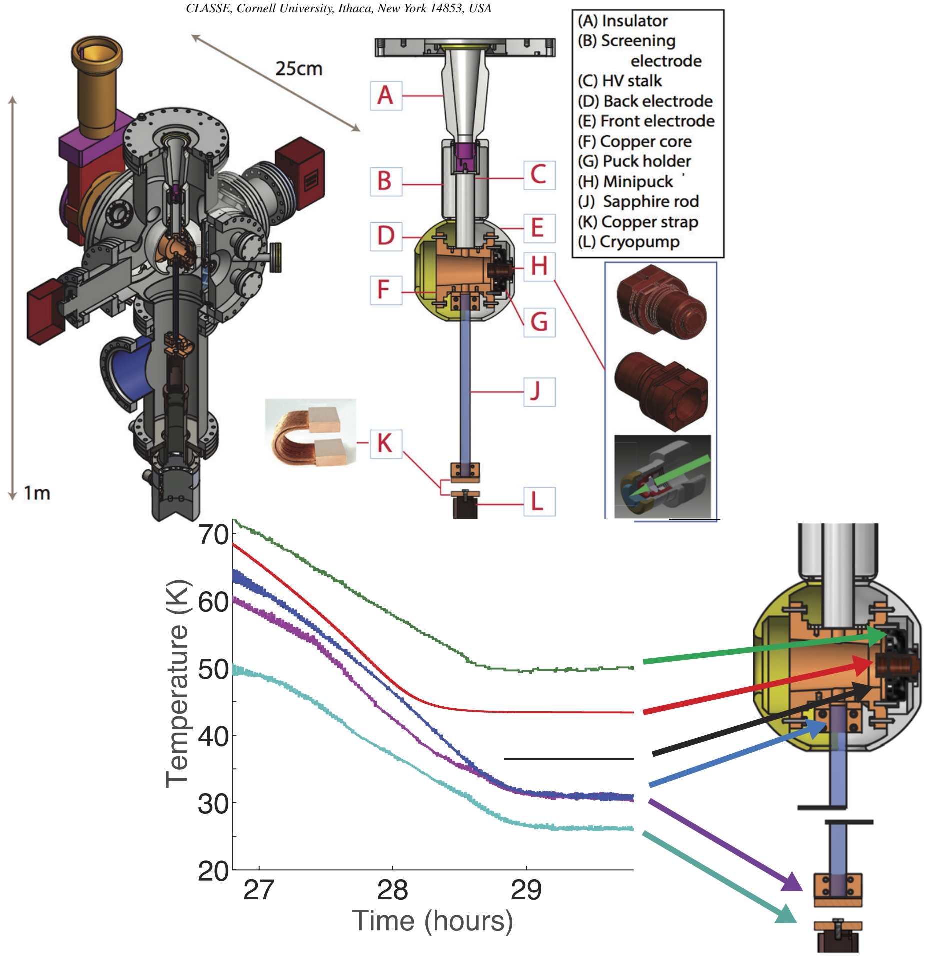
[2]University of Chinese Academy of Sciences, 19A Yuquan Rd., Beijing 100049, China
[3]Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, Virginia 23606, USA
[4]Engineering Research Center of New Energy Technology of Jiangxi Province, East China Institute of Technology, Nanchang 330013, China

REVIEW OF SCIENTIFIC INSTRUMENTS 89, 083303 (2018)

A cryogenically cooled high voltage DC photoemission electron source

Hyeri Lee,[a)] Xianghong Liu, Luca Cultrera, Bruce Dunham,[b)] Vaclav O. Kostroun, and Ivan V. Bazarov
CLASSE, Cornell University, Ithaca, New York 14853, USA



Conclusions and outlook

- The use of alternative coatings to activate GaAs based photocathodes:
  - NEA can be achieved with either Cs-Te and Cs-Sb;
  - Lifetime is improved by a factor of 10x or more;
  - Polarization and QE are affected by thickness;
  - Trades off are required;
- Soon beam tests in a real gun;
- Cryogenic electron sources can be leveraged to increase polarization.
- kCoulomb from PES in sight?

Thank you for the attention!!

Acknowledgements to:

NP-DOE DE-SC0019122
NSF PHY-1549132

collaborators:

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

And the photocathode development group at CLASSE