Electron Source Perspectives for C^3

(at least one person's view)

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Workshop on Future US Colliders, SLAC Jan. 2022

Outline

- Photocathode materials for polarized electrons.
- What is the right polarized electron gun for C^3?
  - DC guns past and future
  - A very high field cryogenic RF photoinjector
- Future directions

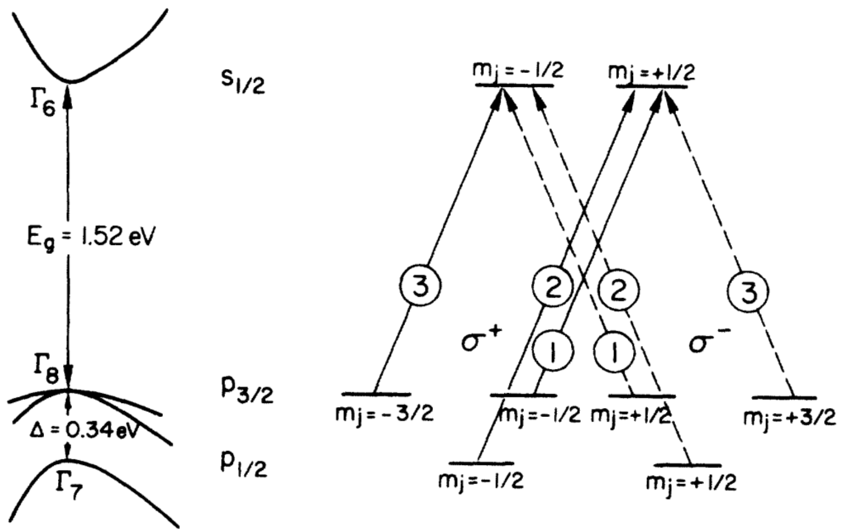
GaAs, still!

- GaAs remains the go-to source of polarized electrons for all next-gen collider designs: EIC, ILC, CLIC, more.
- But there have been several advancements since its inception.

PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier
Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH 8049, Zürich, Switzerland
(Received 10 February 1976)



Band degeneracy:
Maximum polarization of 50%.

With activation with Cs, O, bulk GaAs to yield negative electron affinity, can give QE~10% for bandgap excitation (780 nm).

Excellent intrinsic emittance at 780 nm: 0.25 um/mm rms.

GaAs, still!

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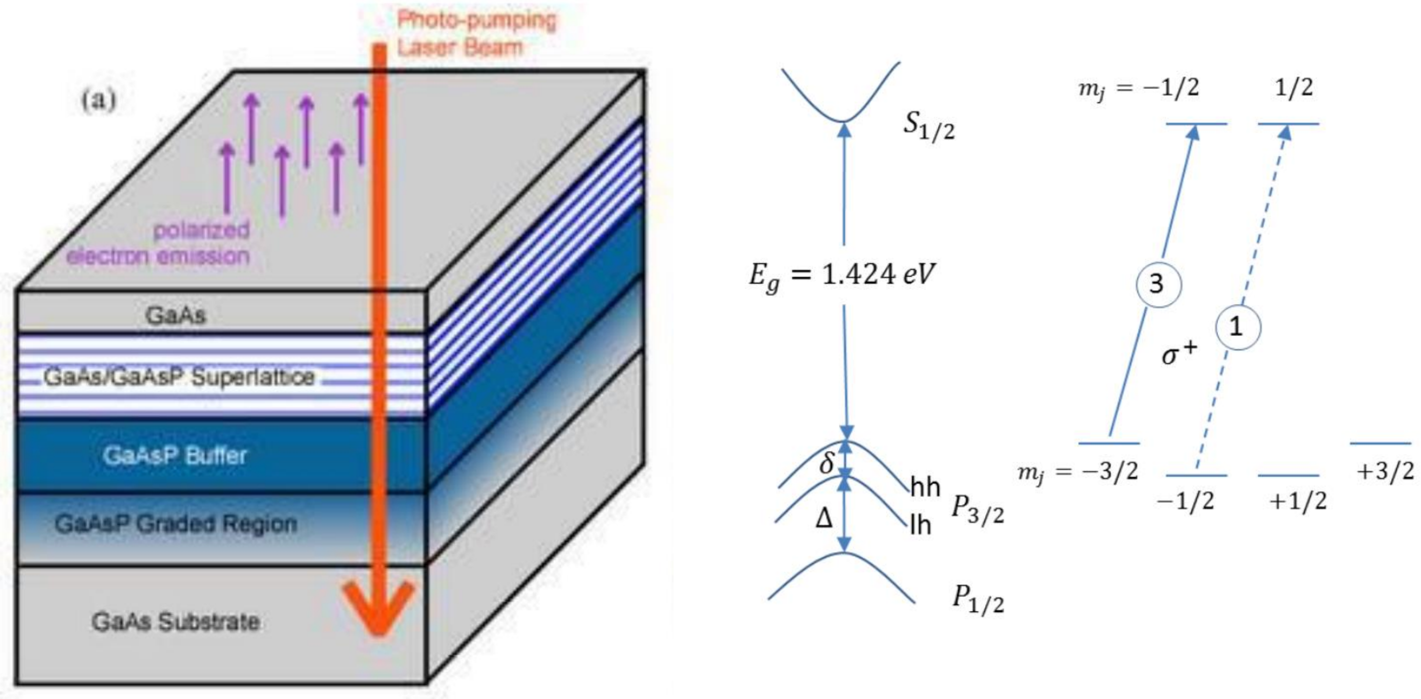
Insight 1: Lift the band degeneracy with strain, ideally via a superlattice.



Very high polarization, >90% measured.

Downside: superlattice is not terribly thick—doesn't absorb much light. QE<1%

Figures from Wei Liu

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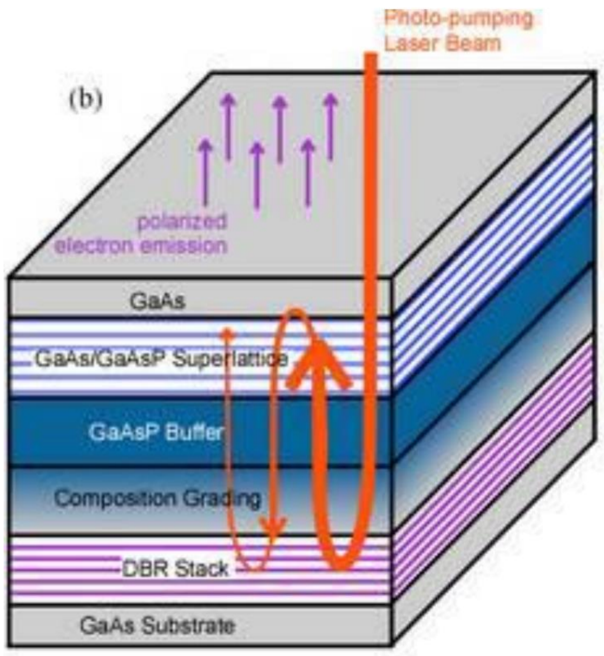
Insight 2: Engineer layer thickness and indices of refraction to engineer absorption via interferometric effects (“Distributed Bragg Reflector”)



DBR photocathode

Record-level quantum efficiency from a high polarization strained GaAs/GaAsP superlattice photocathode with distributed Bragg reflector

Wei Liu,[1,2,3,a)] Yiqiao Chen,[4] Wentao Lu,[4] Aaron Moy,[4] Matthew Poelker,[3] Marcy Stutzman,[3] and Shukui Zhang[3]

QE enhanced to >6%, with polarization of 84%.

Downside? Not really! Will increase temporal response time to on the 10s of picosecond scale, but this is not important for large bunch charges.

Figures from Wei Liu

Vacuum Sensitivity

- The main challenge with NEA GaAs photocathodes:

  A sub-monolayer of Cs/O activates the surface, and so a sub-monolayer of reactive gas can kill it.
- Can be rejuvenated with heating cycle and recesiation (hours).
- Operating pressures of polarized photoguns to date are typically $<10^{-11}$ torr.

- This explains an important fact: EIC, CLIC, ILC designs intend to use DC photoguns with very pure vacua.

DC guns

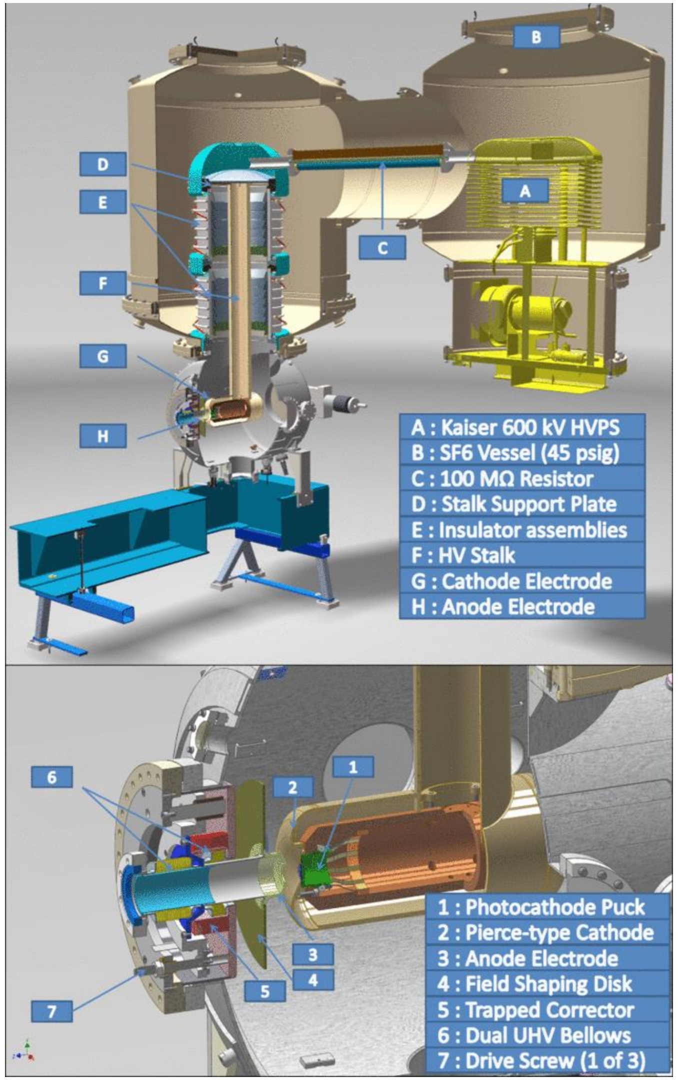
Example 1

Cornell MK-II
KEK-inspired, 450 keV
Tunable gap

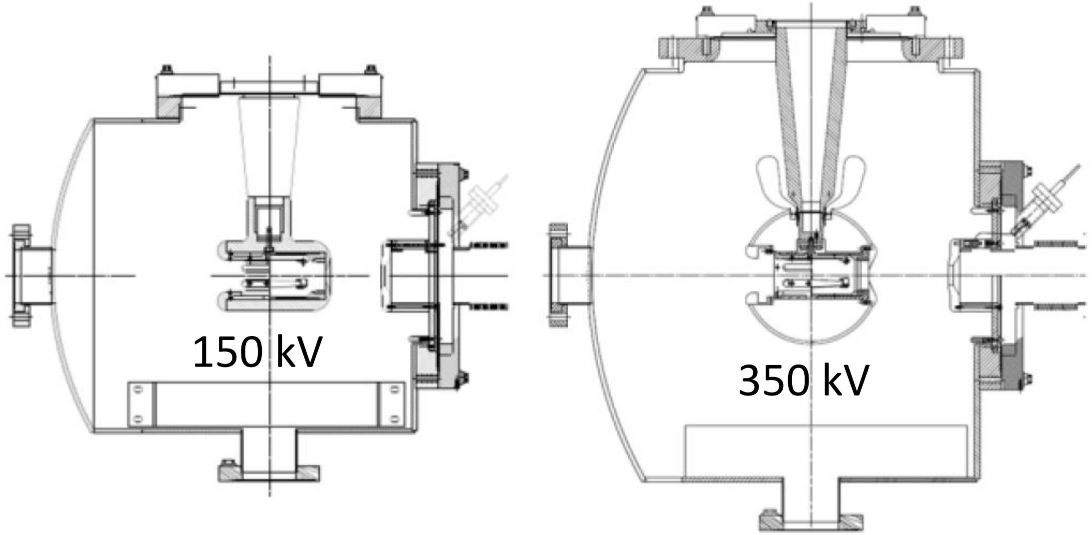
Geometry typical of highest energy designs

5 MV/m field at 450 kV.

Cathode insertion from back, not shown.



Example 2



Inverted guns: simple and compact! In production at JLAB, and now BNL.
Similar field, slightly lower voltage. The future!

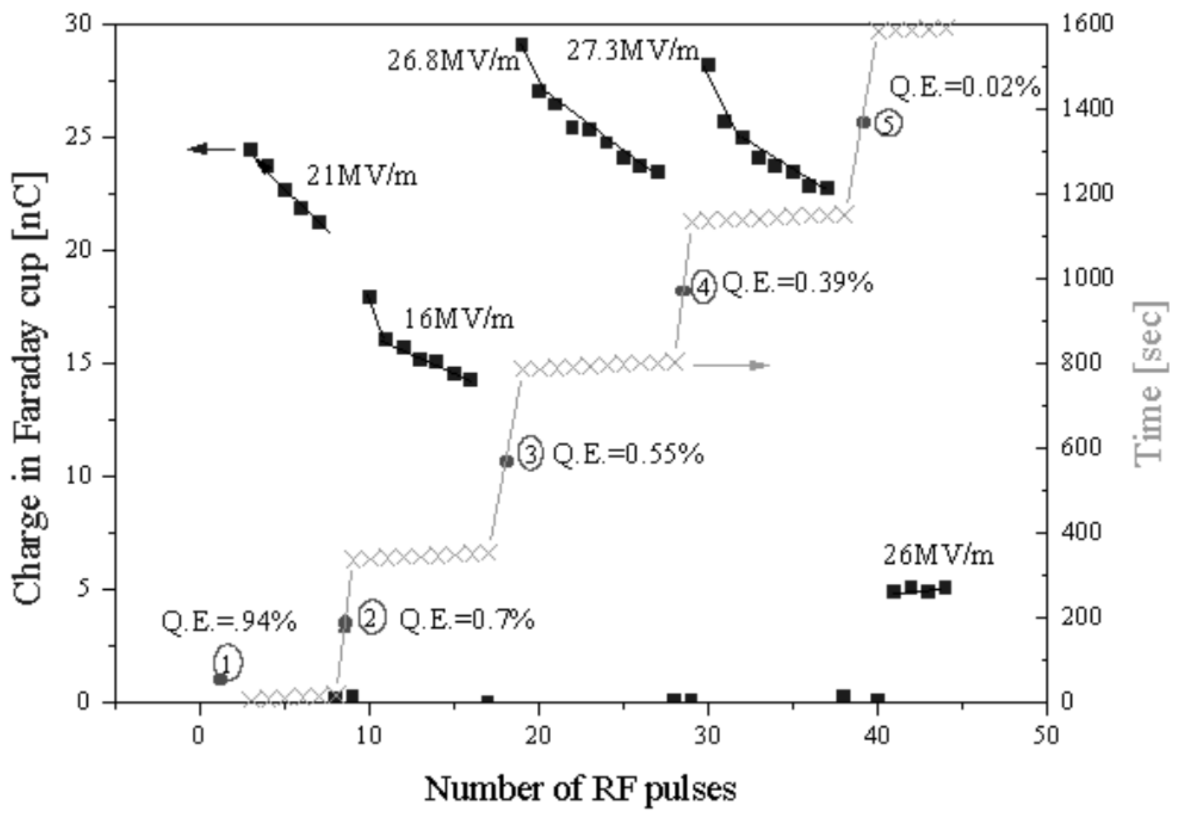
Developed originally at SLAC: M. Breidenbach et al., NIMA, 1994.

Novosibirsk RF test of GaAs

- There has been at least one test of GaAs:Cs/O in a 100 MV/m S-band RF gun:

EXPERIMENTAL STUDY OF GaAs PHOTOCATHODE PERFORMANCE IN RF GUN*

A.V.Aleksandrov, N.S.Dikansky, R.G.Gromov, P.V.Logatchov, BINP, Novosibirsk, Russia



- Very good base pressure considering challenging vacuum conductance of S-band guns: 2×10^{-10} torr
- Short lifetime
- Authors also note multiple orders of magnitude growth in dark current w.r.t. nominal
- Work function of NEA GaAs is only 1.6 eV (compare to ~4.4 eV for Cu).

Need for Field

- But: a strategic advantage of C^3 and cryogenic copper is extreme field, ~2 orders of magnitude above DC guns.
- Transverse brightness from gun: $B_{max} \propto E_{cath}^{3/2}$
- The big source question in my mind is: Can we merge cryo-RF and polarized photoemission?
- Big opportunities:
  - – greatly simplify injector
  - – can even consider ultimately removing e- damping ring
- Big challenge: need to work hard on this *now*.

Performance of Cryo-RF gun

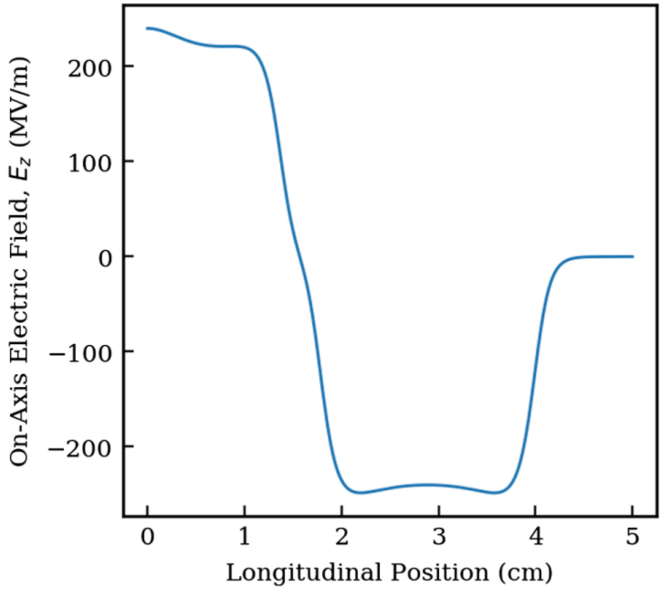
- C-band design for 100 pC, magnetized beam for asymmetric emittance.

PHYSICAL REVIEW ACCELERATORS AND BEAMS **24**, 063401 (2021)

Editors' Suggestion

Versatile, high brightness, cryogenic photoinjector electron source

River R. Robles,*,† Obed Camacho, Atsushi Fukasawa,
Nathan Majernik, and James B. Rosenzweig



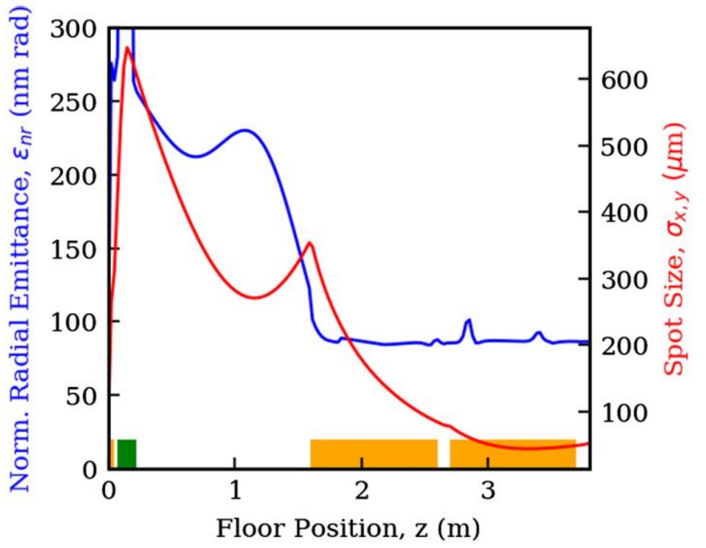
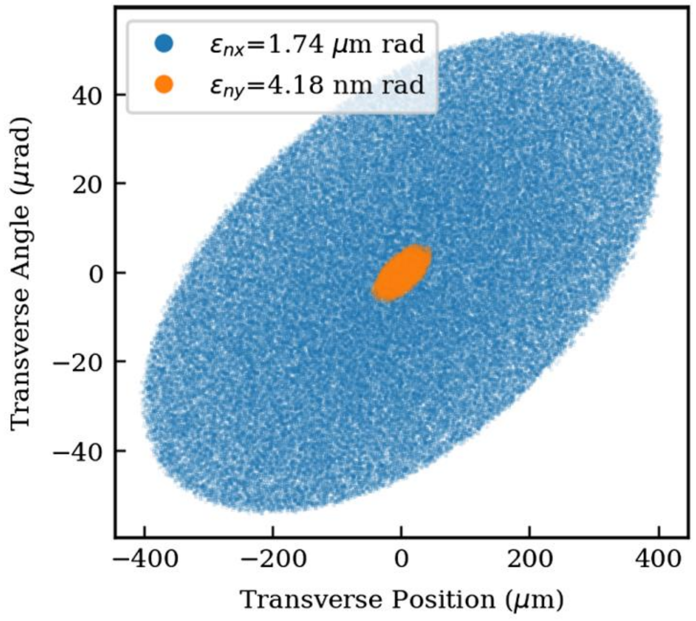


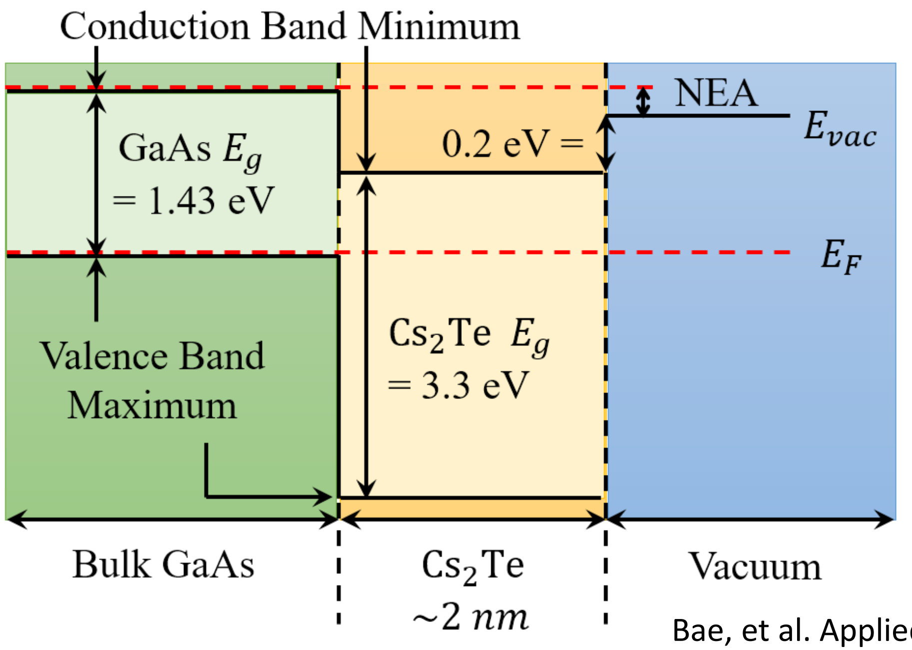
FIG. 14. The emittance and beam size evolution of the magnetized operating point are shown up to the entrance to

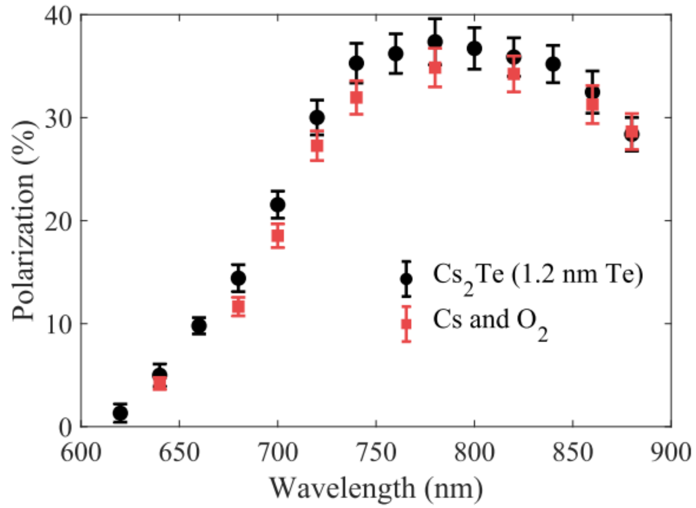


What about for 1 nC? C-band may be challenging, but an S-band source is a promising alternative

Beyond activation with Cs/O

- Are there more robust activating layers?
- Uchida et al, IPAC 2014: GaAs can be activated with Cs-Te!
  - Cs-Te photocathodes are the LCLS-II baseline, regular operation at 50 MV/m in PITZ, European-XFEL, others.
- Cornell: Cs-Te activation preserves polarization and improves lifetime by at least 5x w.r.t. Cs/O.



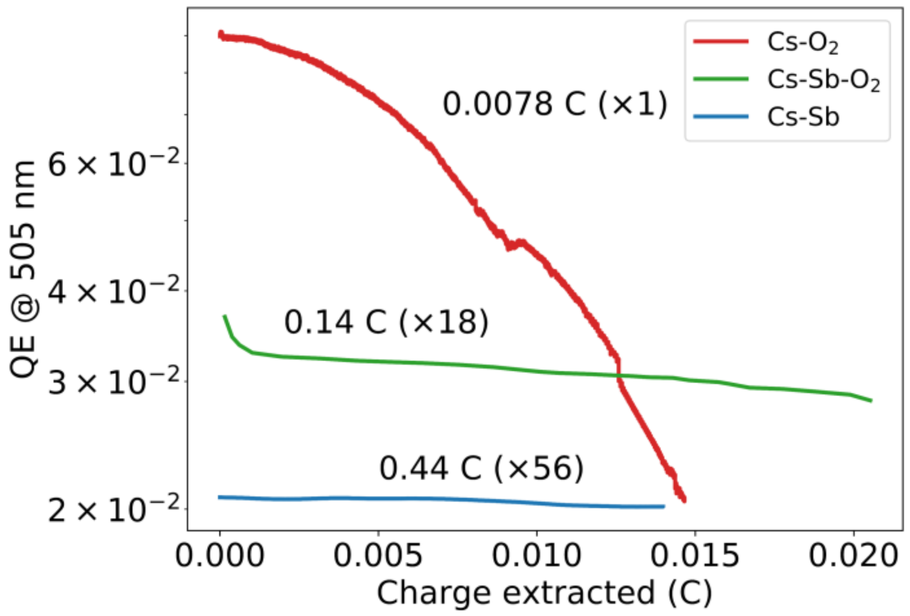


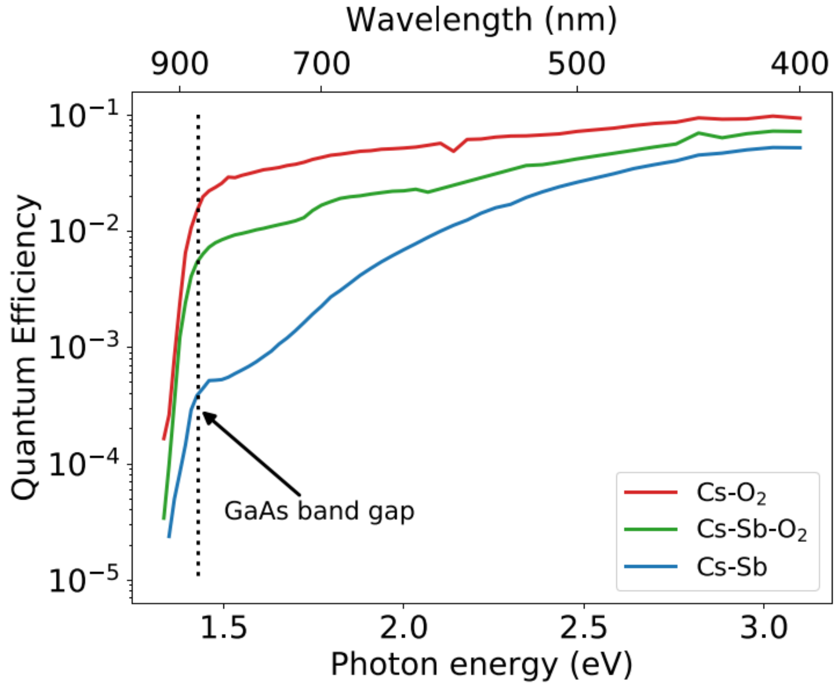
Bulk GaAs

Bae, et al. Applied Physics Letters 112.15 (2018): 154101.

Beyond activation with Cs/O

- Another rugged activating layer: Cs-Sb
- Orders of magnitude lifetime improvement.



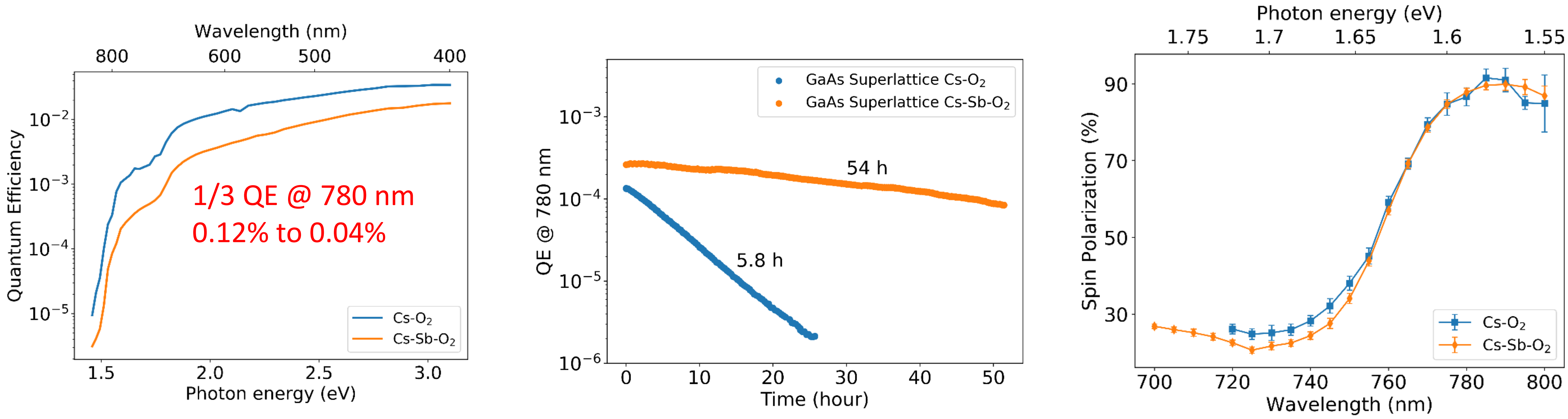


Bae *et al, NAPAC 2019, MOPLH17*

Bae *et al, Journal of Applied Physics*. **127**, 124901 (2020)

Superlattice Activation with Cs-Sb

- High polarization (90%) preserved with Cs-Sb activating layer.
- Much thicker layers provide even longer lifetime at the expense of QE and polarization.



Bae *et al*, *Journal of Applied Physics*. **127**, 124901 (2020)

- Would be very interesting to try on a DBR sample (high QE)!

Looking Ahead

- Urgent need for more testing of high QE materials in RF photoguns: efforts at UCLA, LANL, PITZ, …
- Can we look beyond GaAs? GaN (3.4 eV bandgap) is a possibility that we are currently exploring.
- More exotic coatings? Perhaps coat the activating layer with a 2-D material like Graphene or HBN? Efforts at BNL, LANL, others

Thanks!

The Cornell Polarized Photocathode Team: Jai Kwan Bae, Alice Galdi, Luca Cultrera, Matthew Andorf, Jared Maxson, Ivan Bazarov

Thanks to The Center For Bright Beams, NSF, DOE HEP, and DOE NP for funding!