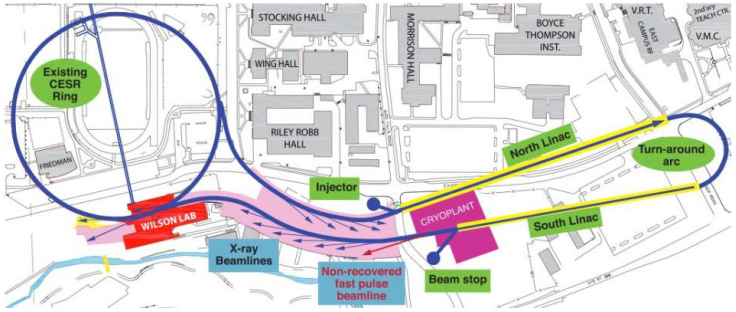
Photocathodes for High Current Electron Guns

L. Cultrera

High average current photoinjector applications

- **ERL based x-ray sources**



Bunch charge	77 pC
Average current	**100 mA**
Energy	5 GeV
Norm. tran. emitt.	0.3 mm mrad

- **Electron-ion collider**

Bunch charge	300 pC
Average current	**6.4 mA**
Energy	60 GeV
Norm. tran. emitt.	30 mm mrad

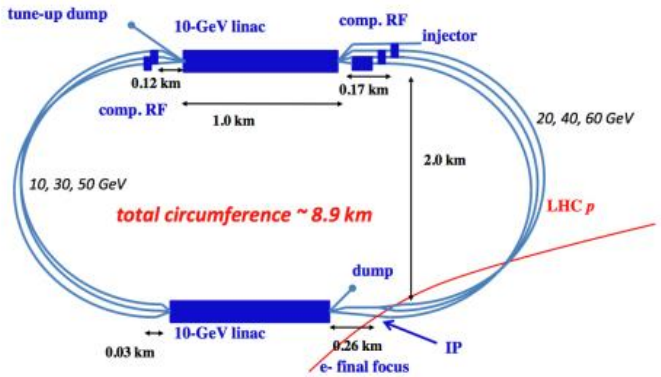
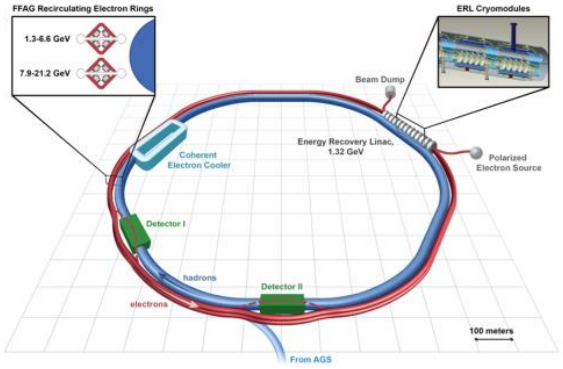


Figure 7.5: LHeC ERL layout including dimensions.

- **Electron cooling of hadrons**

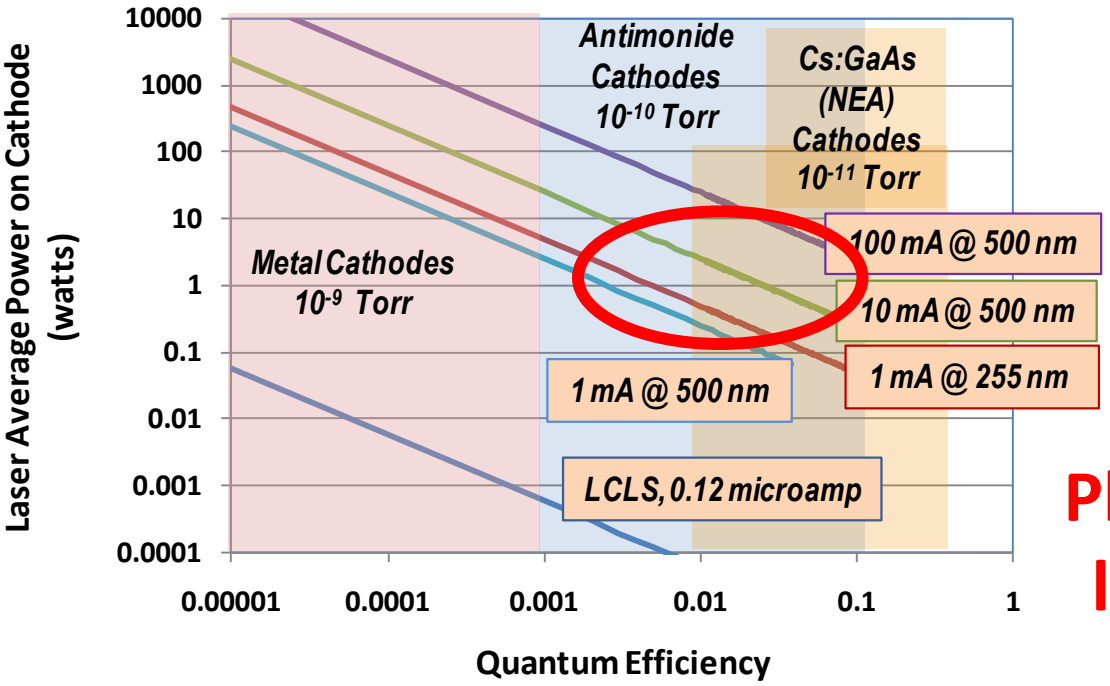


Bunch charge	5300 pC
Average current	**50 mA**
Energy	15.9 GeV
Norm. tran. emitt.	30 mm mrad

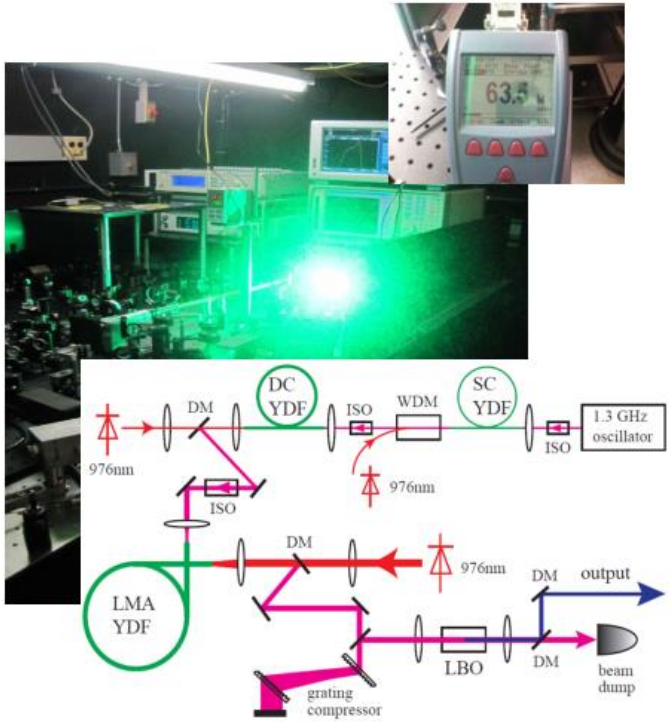
POLARIZED!!

Photocathode requirements

- High Quantum Efficiency
- Low intrinsic emittance
- Fast response time
- Ruggedness



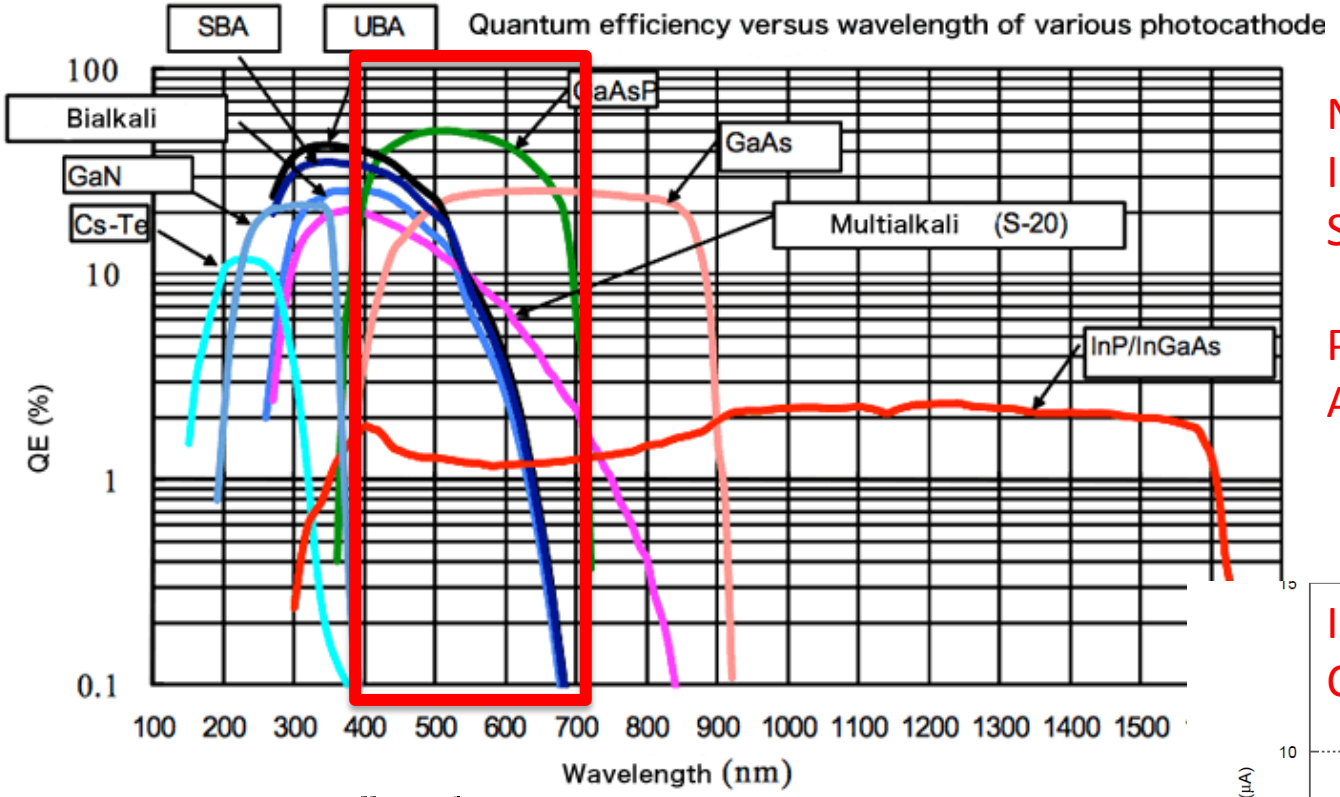
D. Dowell, Photocathode Physics for Photoinjectors Workshop, BNL October 2010



Z. Zhao, B.M. Dunham, I.V. Bazarov, F.W. Wise, Optics Express 20 (2012) 4850

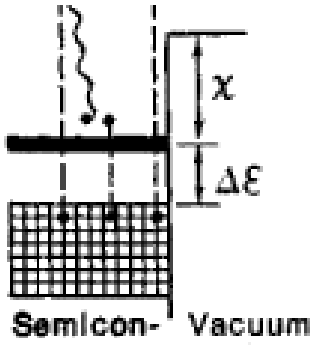
Photocathode choice still limited to few materials

Photocathode materials

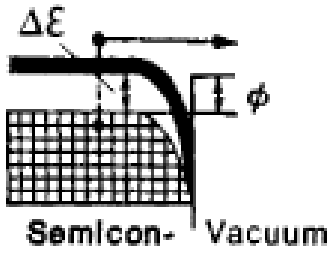


Negative Electron Affinity
III-V semiconductors
Superlattices

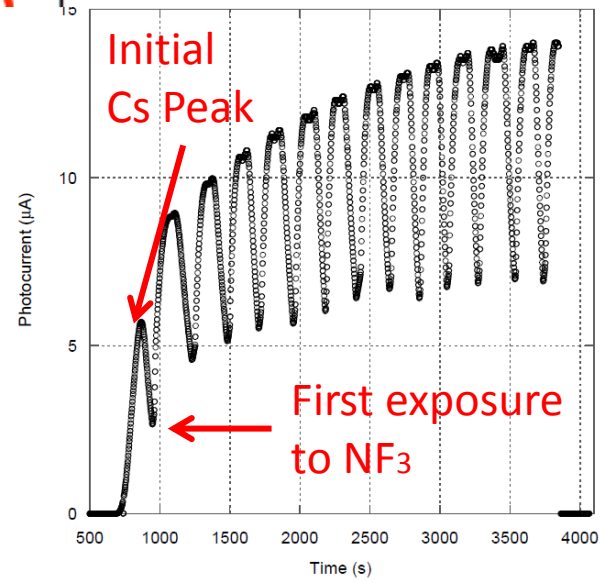
Positive Electron Affinity
Alkali antimonides



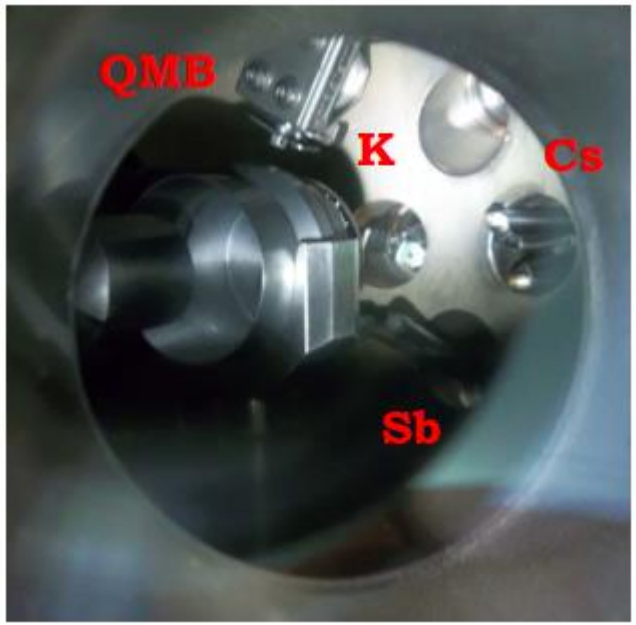
PEA



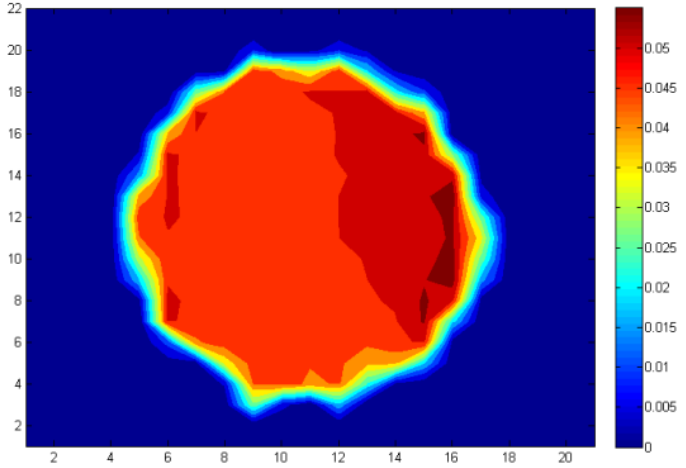
NEA

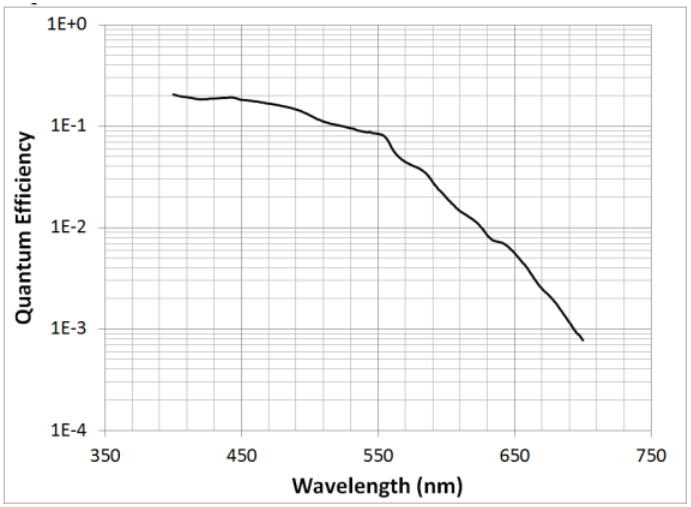


Alkali antimonide growth



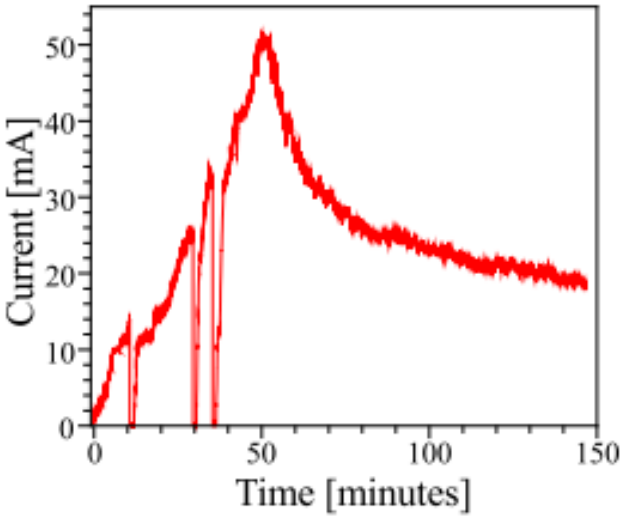
Cs_3Sb, CsK_2Sb, Na_2KSb photocathode are grown in the form of thin film by thermal evaporation in UHV over a suitable conducting substrate





GaAs vs Alkali Antimonides

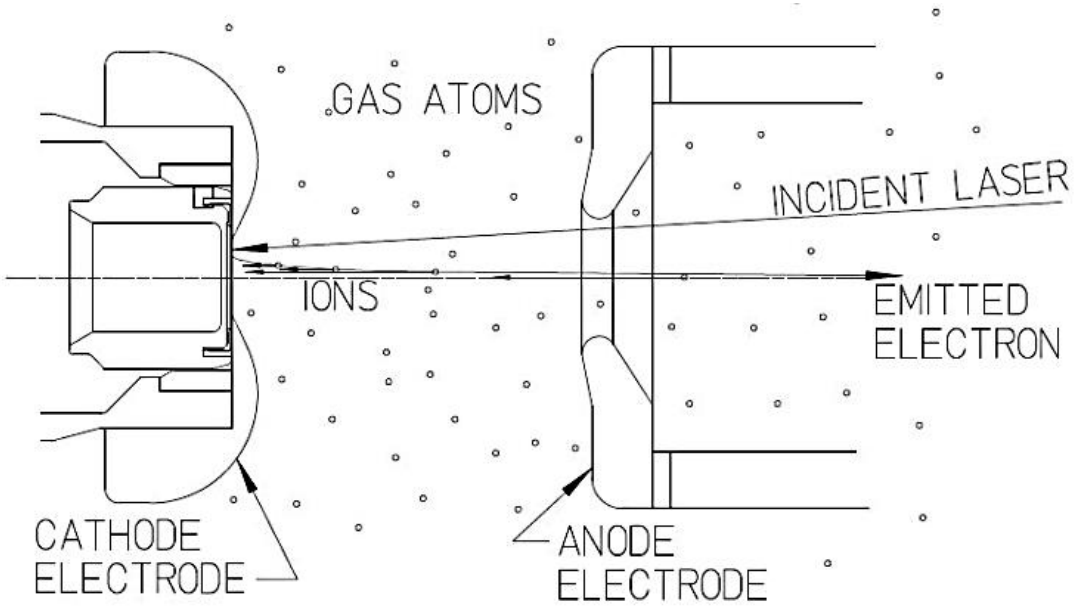
	GaAs	Alkali antimonides
QE @ 532 nm	Exceed 15 %	Between 5 and 10% (depending on growth conditions and materials)
Intrinsic emittance @ 532 nm	0.47 mm mrad / mm rms	0.56-0.48 mm mrad / mm rms
Response time @ 532 nm	Less than a ps	Less than a ps
Vacuum sensitivity	**Very High (survive days in 10^{-11} Torr)**	**High (survive months in 10^{-11} Torr)**



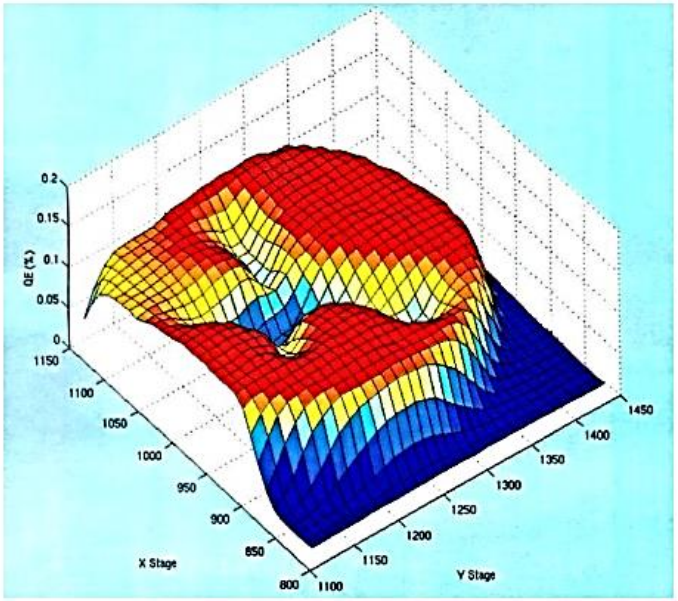
GaAs cannot withstand high current levels (>20 mA) for very long times

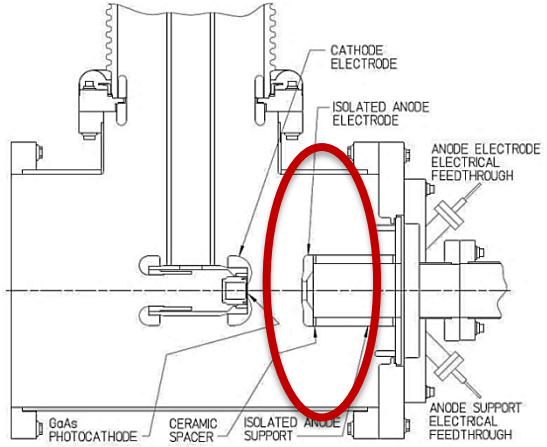
B Dunham et al., Applied Physics Letters 102 (2013) 034105

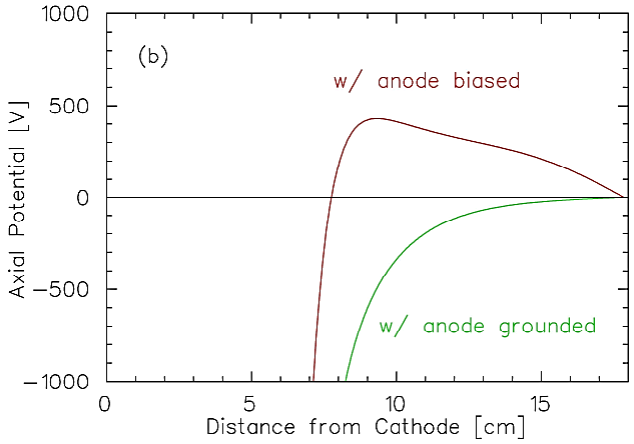
GaAs and ions back bombardment

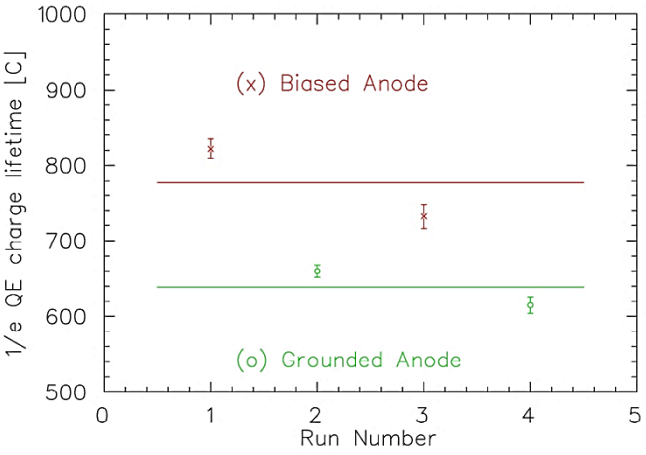


J Grames et al., AIP Conf. Proc. **980**, 110 (2008)

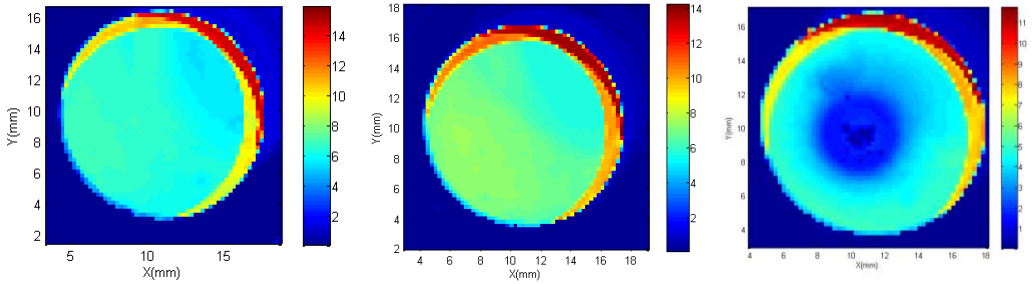








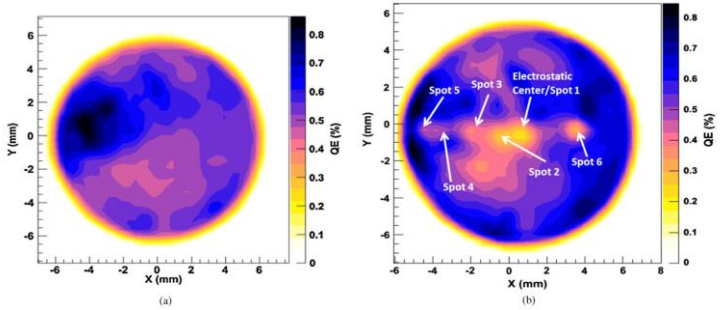
Alkali antimonides ion back bombardment

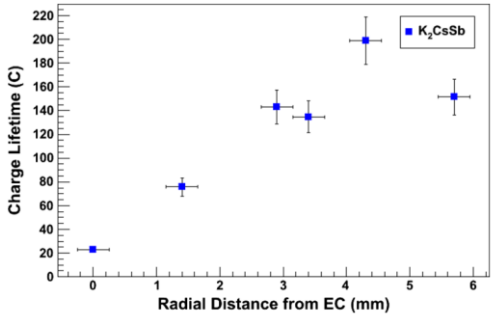


Fresh cathode

~10 mA
2 hours
No RF trips

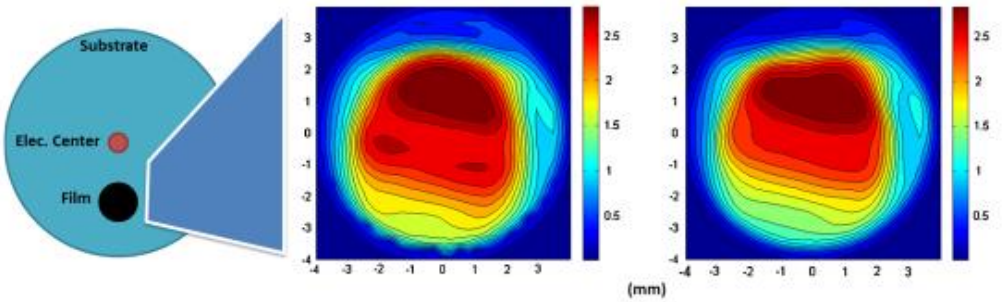
~20 mA
2 hours
many RF trips

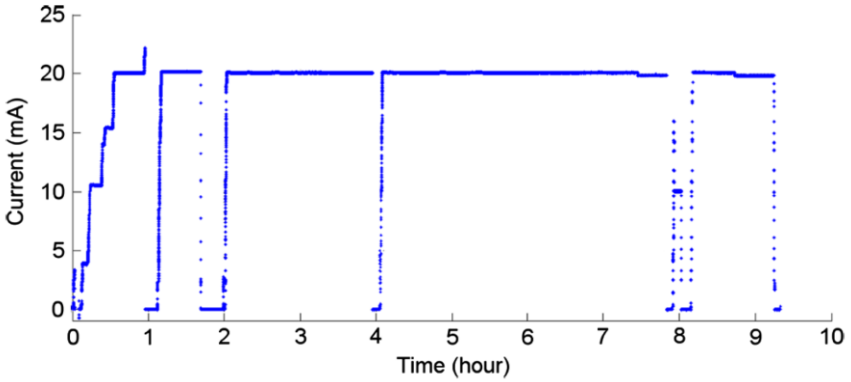


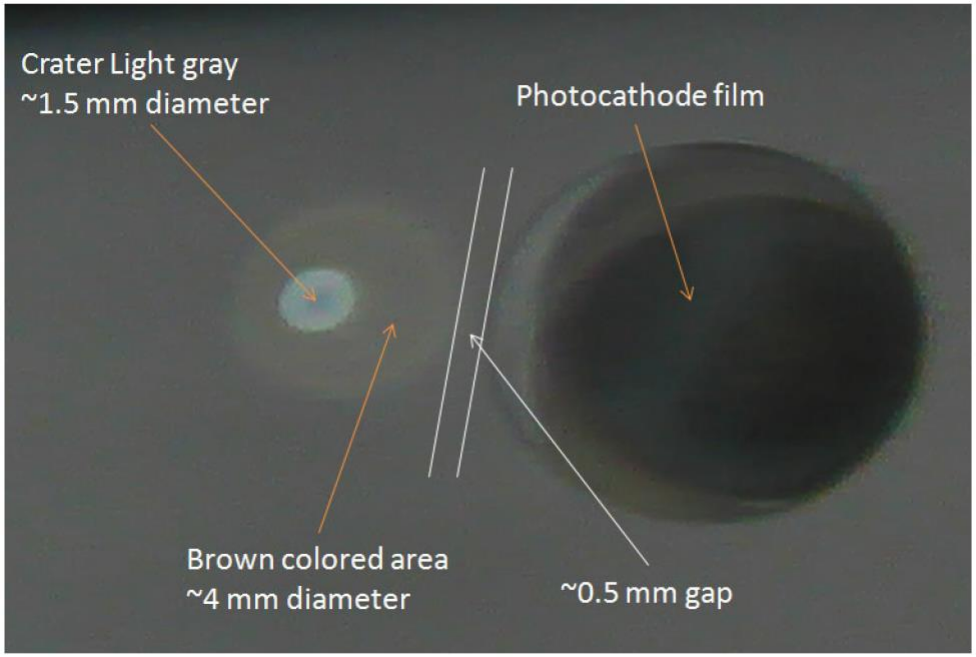


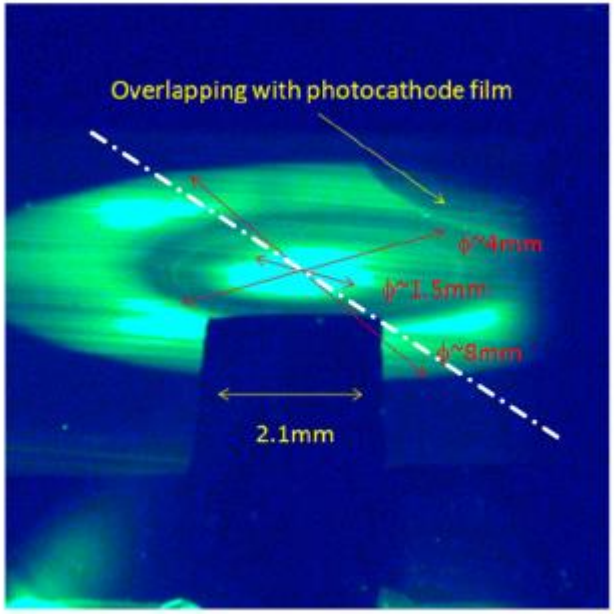
Stay away from the electrostatic center!

Cathode offset from center

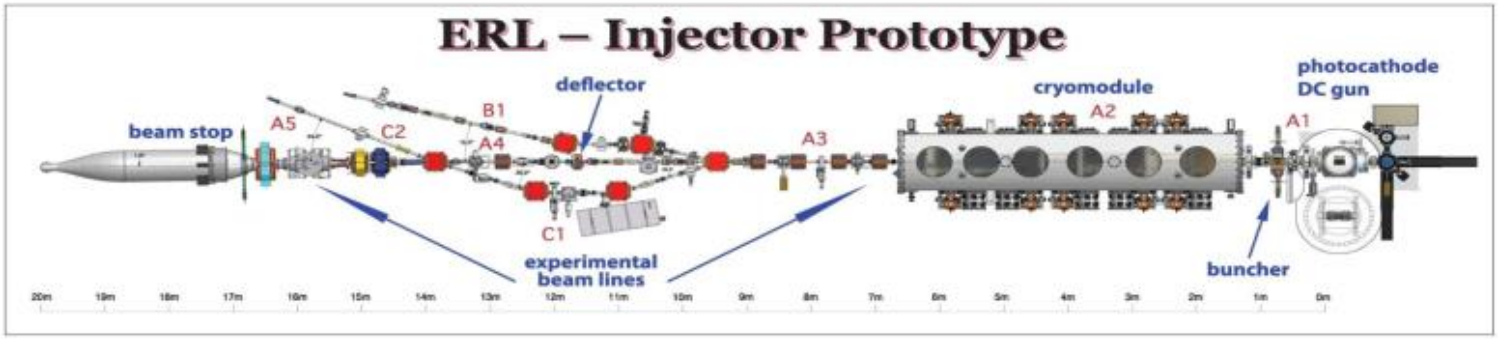






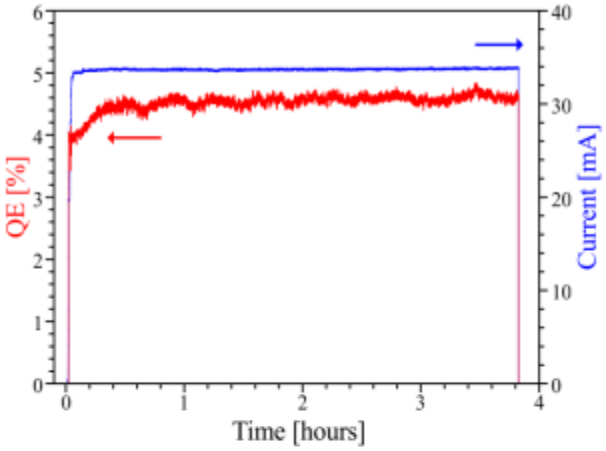


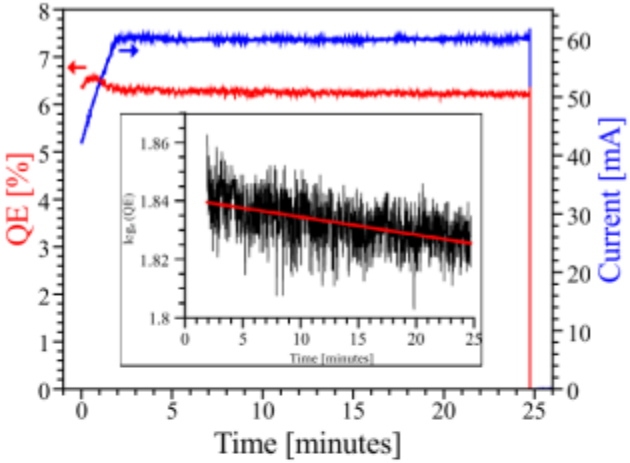
The Cornell photoinjector

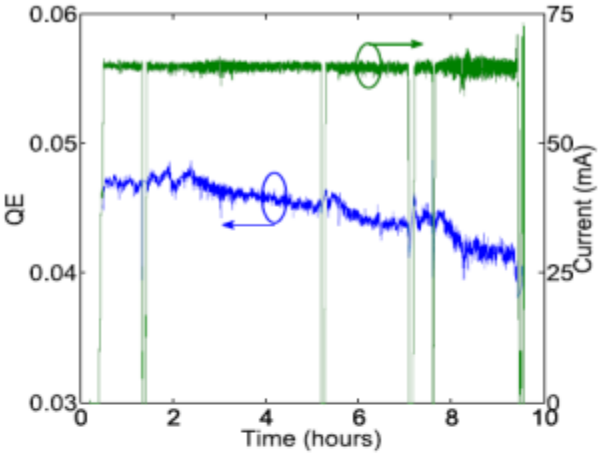


Parameter	Metric	Status	Notes
Average Current	100 mA		65 mA at 4 MeV (1300 MHz)
Bunch Charge	77 pC		Pulsed mode (50 MHz)
Energy	5 to 15 MeV		14 MeV max (due to cryo limits)
Laser Power	> 20 W		> 60 W at 520 nm (1300 MHz)
Laser Shaping	beer can dist.		Adequate for now
Gun Voltage	500-600 kV		Currently operating at 350 kV
Emittance	<0.5 μm (norm, rms)		Ultimate ERL goal 0.3 μm, with merger
Operational Lifetime	> 1 day		Recent improvements with new cathodes

High average current runs







Cs_3Sb
QE @ 520 nm 4%
Max AVG current 33 mA
Lifetime >> 500 C
NO QE DECAY

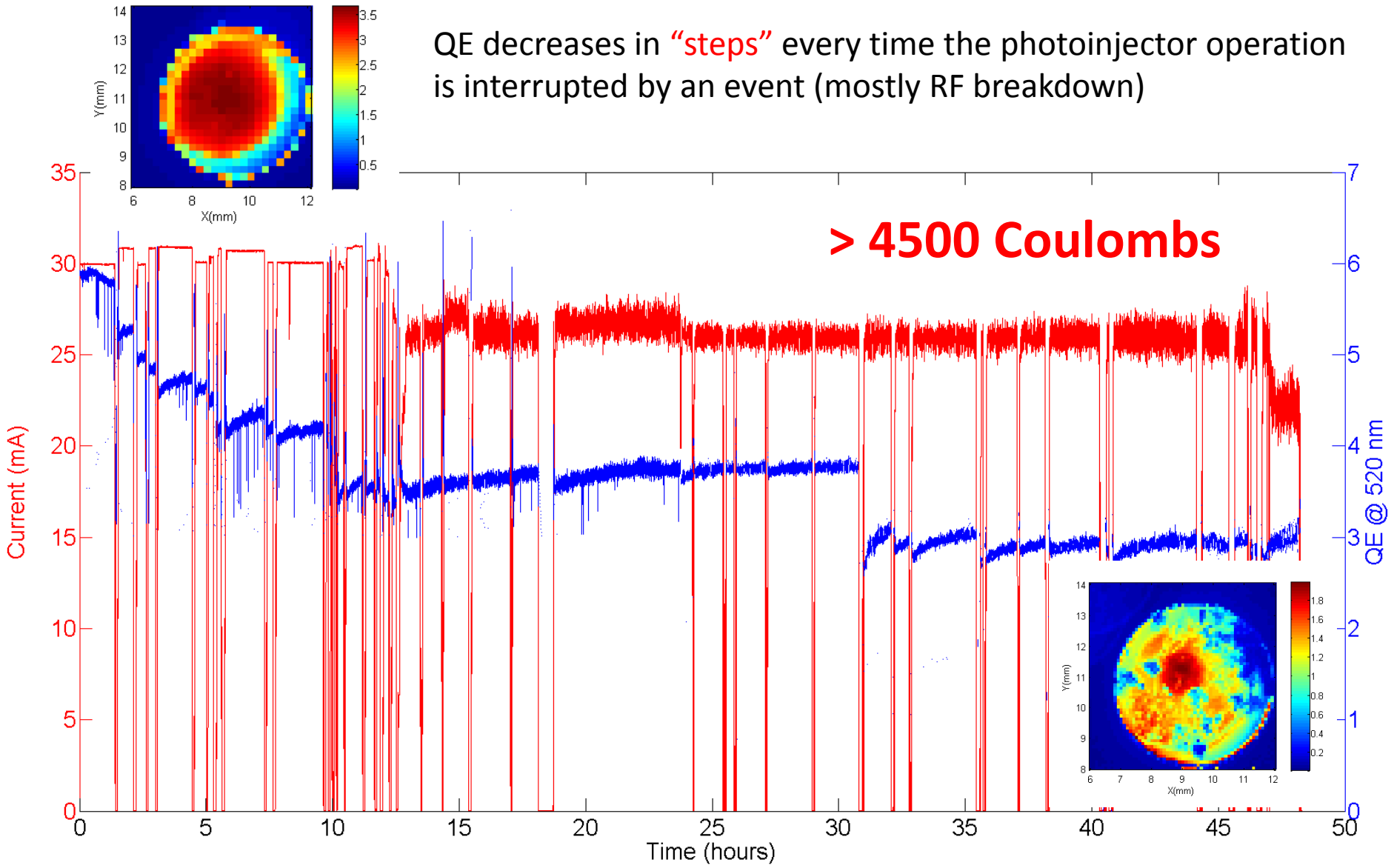
Cs_2KSb
QE @ 520 nm 6.5%
Max AVG current 60 mA
Lifetime >> 2000 C
1/e QE 30 hr

Na_2KSb
QE @ 520 nm 4.5%
Max AVG current 65 mA
Lifetime >> 2000 C
1/e QE 66 hr

Alklai antimonide based photocathode have been extensively tested in DC gun of the ERL injector prototype at Cornell University. MTEs, response time, QEs and lifetimes at high current are compatible with the operation of an ERL user facility.

Na_2KSb: 48 hours long run

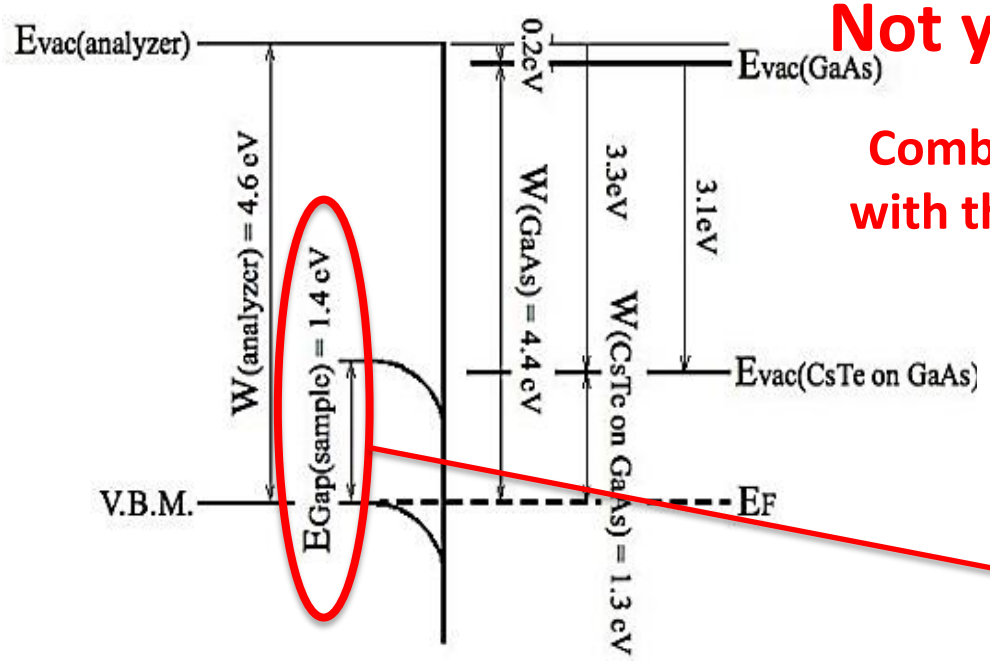
QE decreases in "steps" every time the photoinjector operation is interrupted by an event (mostly RF breakdown)

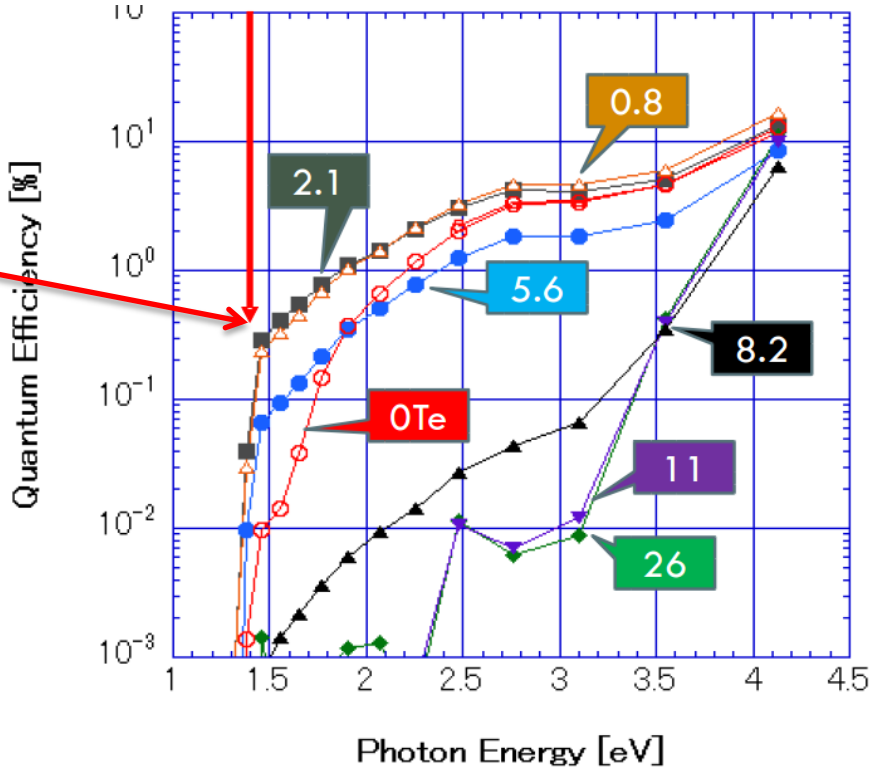


Thin CsTe on GaAs

Not yet used in any electron gun

Combine the ruggedness of solar blind CsTe with the high sensitivity of GaAs in the VIS-IR





Improve lifetime of GaAs and of strained superlattices photocathodes used to generate **polarized electron beams**

SL with QE of 0.5% require 15 W of laser power on the cathode for generating 50 mA

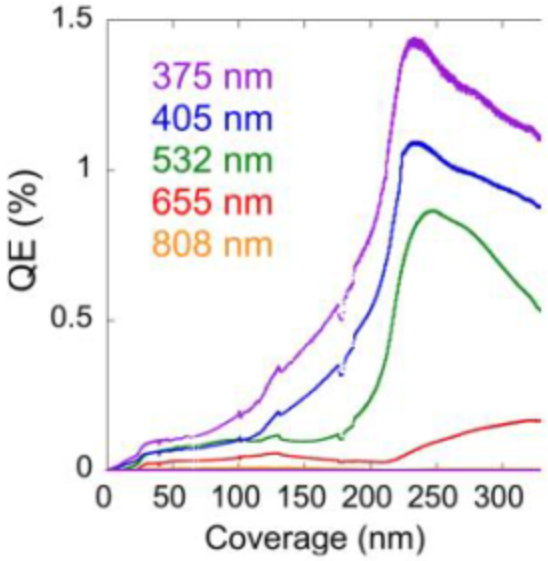
M. Kuriki et al., IPAC 2015

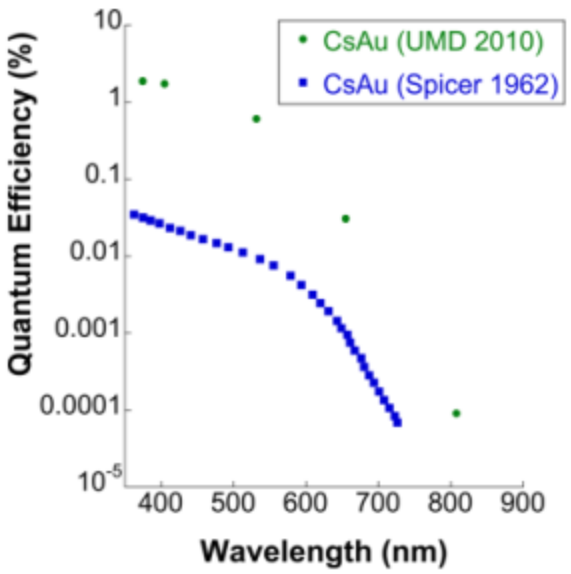
Cesium Auride

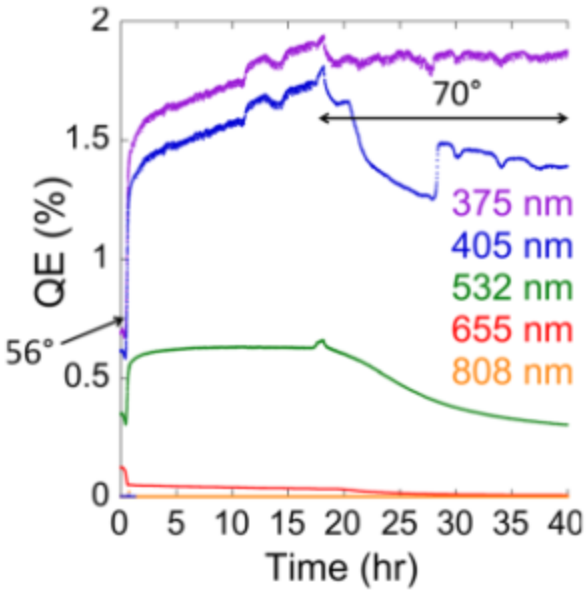
As was to be expected, the alloys of the Au*M* type are photo-electrically sensitive, but the sensitivity is too low to be of practical importance. An

A. Sommer, Nature **152**, 215 (1943)

~0.5 W of VIS laser / mA average current !!!







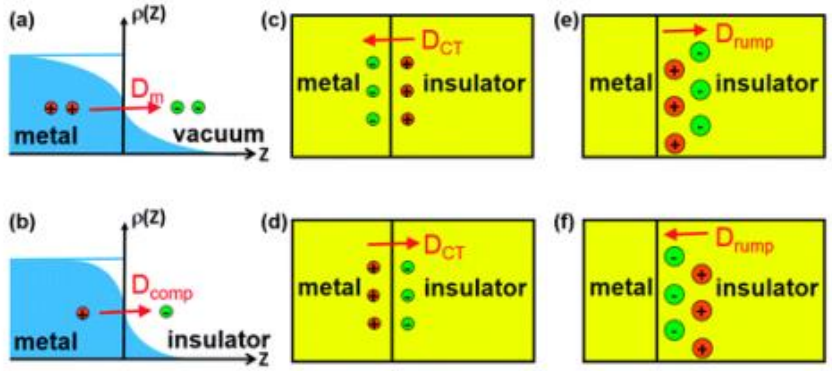
- These results **reopen** the question of AuM semiconductors
- QEs in the range of few % can be achieved in the visible
- Lifetime properties at room and moderate temperature are encouraging
- MTE, Response Time yet to be characterized

S. A. Khan, *J. Vac. Sci. Tech B* **30**, 031207 (2012)

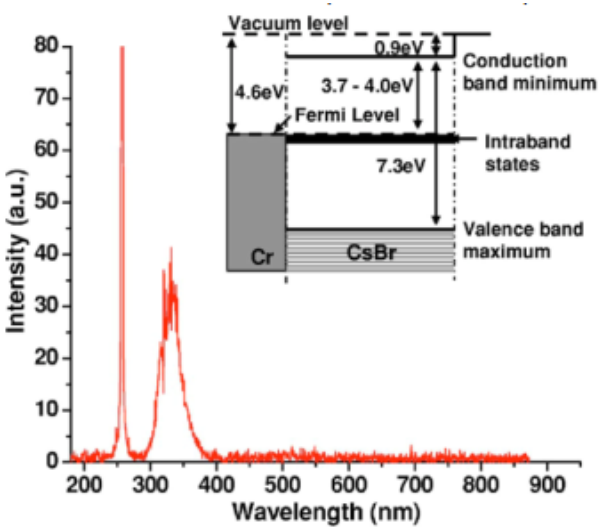
Coated metals

Possible way to enhance QE of metals:

- Reduction of workfunction
- Emission from intra-band states of insulating coatings



S. Ling et al, *Phys. Chem. Chem. Phys.* **15**, 19615 (2013)



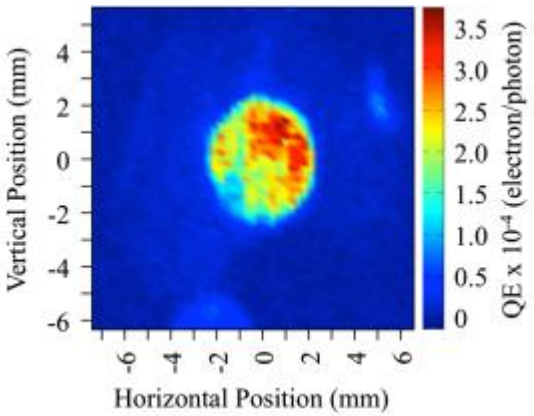
Z. Liu et al., *Appl. Phys. Lett.* **89**, 111114 (2006)

266 nm	KBr	CsBr	CsI
Film thick. (nm)	7	7	8
QE enh. b.a.	1.8	14	18
QE enh. a.a.	2.6	77	2700
WF b.a. (eV)	3.96	3.76	3.68
WF a.a. (eV)	3.66	3.41	1.74

W. He et al, *Appl. Phys. Lett.* **102**, 071604 (2013)

L. Kong et al., *Appl. Phys. Lett.* **104**, 171106 (201 4)

~0.5 W of UV laser / mA average current !!!



With CsBr coating intrinsic emittance is 3x worse than bare Cu

2.63 mm mrad / mm

T. Vecchione, Phys. Rev. ST Accel. Beams 18, 040701 (2015)

Conclusions

- In the last few years lot of progress
  - The 100 mA level photocurrent milestone is within reach
  - Operational lifetimes have been largely improved due to extreme vacuum achievable in DC gun
- In the near future
  - CsTe looks promising in improving lifetime of III-V based photocathodes
  - New promising materials that need to be fully characterized

Thank you!