Photocathode Research @ Cornell

Jared Maxson

On behalf of

Luca Cultrera, Ivan Bazarov, and the entire Cornell photoemission team

IPAC 2019

Photocathode Research @ Cornell

Photocathodes for high brightness applications

Long Lifetime Polarized photocathodes

Photocathodes for photodetector applications

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Photocathodes for high brightness applications

We think broadly about high brightness applications:

- ERL @ Cornell: *Cbeta (See posters by C. Gulliford)*
- Femtosecond electron diffraction, microscopy and spectrosocpy
- XFEL light sources

Exploring a wide array of materials:

- Full family of alkali antimonides
- CsTe
- GaAs and GaN
- Quantum materials (like topological insulators)
- Ever growing…

The "master equation" :

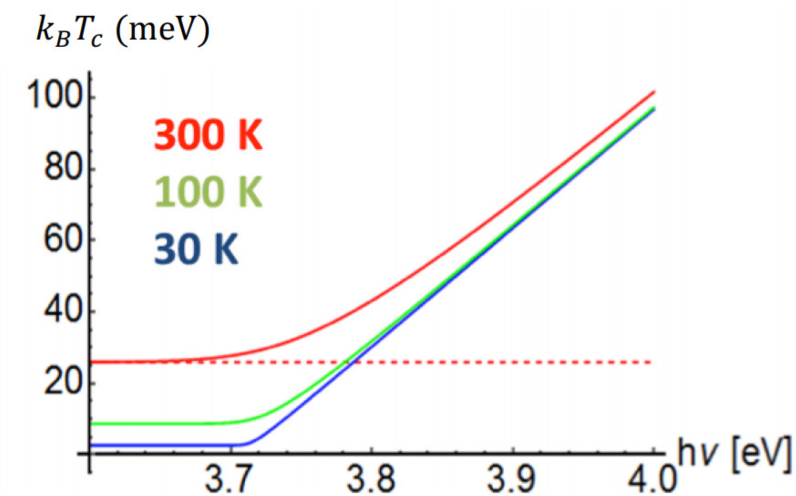
$$B_{max} = B_{source} \propto \frac{E_{cath}^{n}}{kT_e}$$

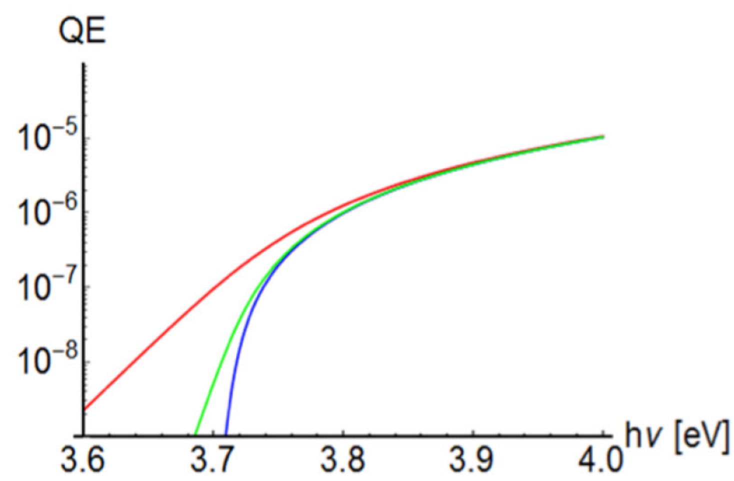
$n \geq 1$ (depends on specifics)

Effective beam temperature at the source

How do you reduce kT_e?

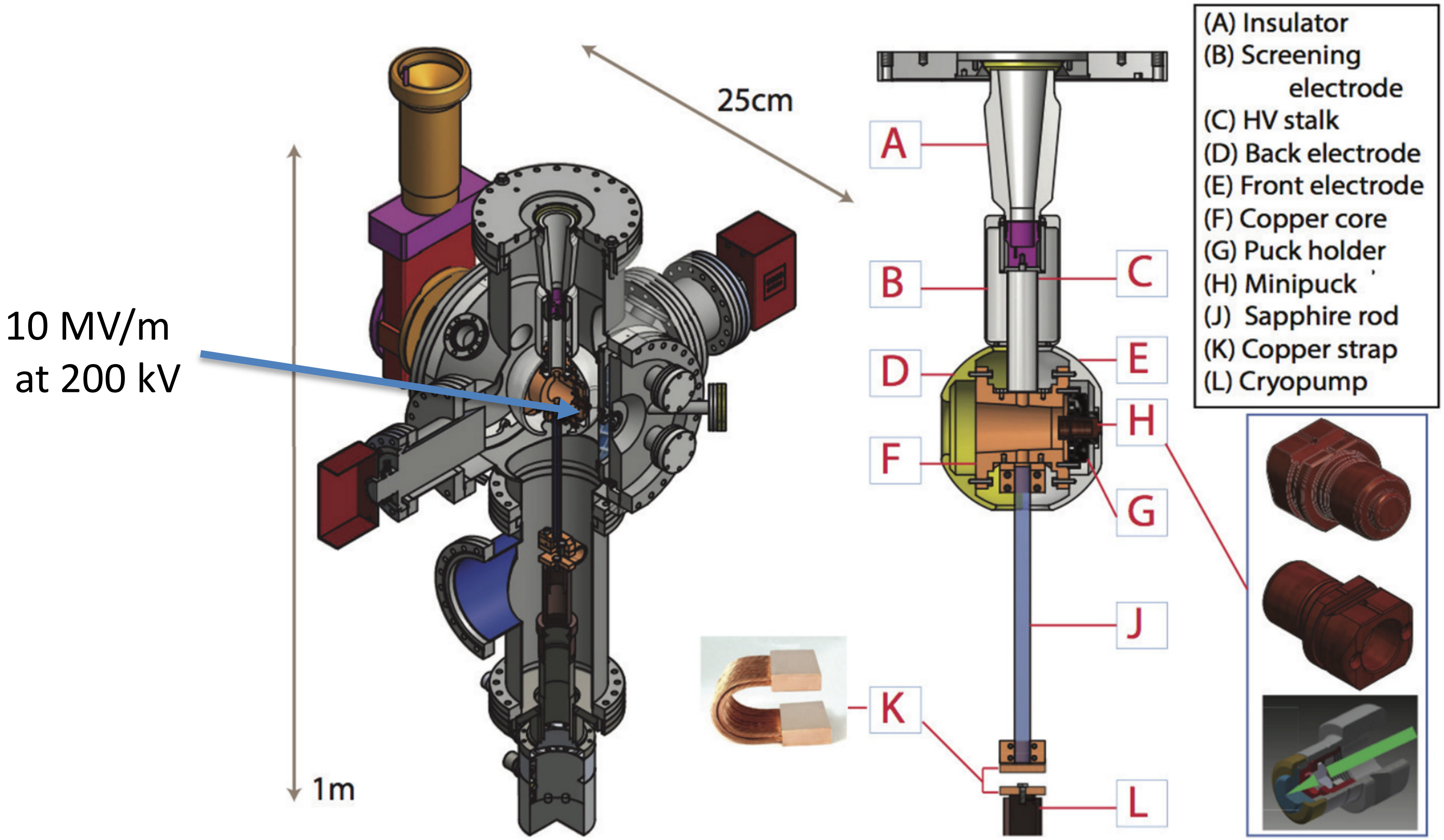
- For a free electron metal, where $E = \frac{(\hbar k)^2}{2m_e}$, here Cu:





- **Big potential gains for low T operation**. 30 K -> ~3 meV, >30x less than typical Cu in RF photoinjectors.
- Penalty: you're emitting from the Fermi tail—not many electrons there!
- S. Karkare et al: extreme low kT_e (6 meV) result from cold Cu (publication forthcoming).

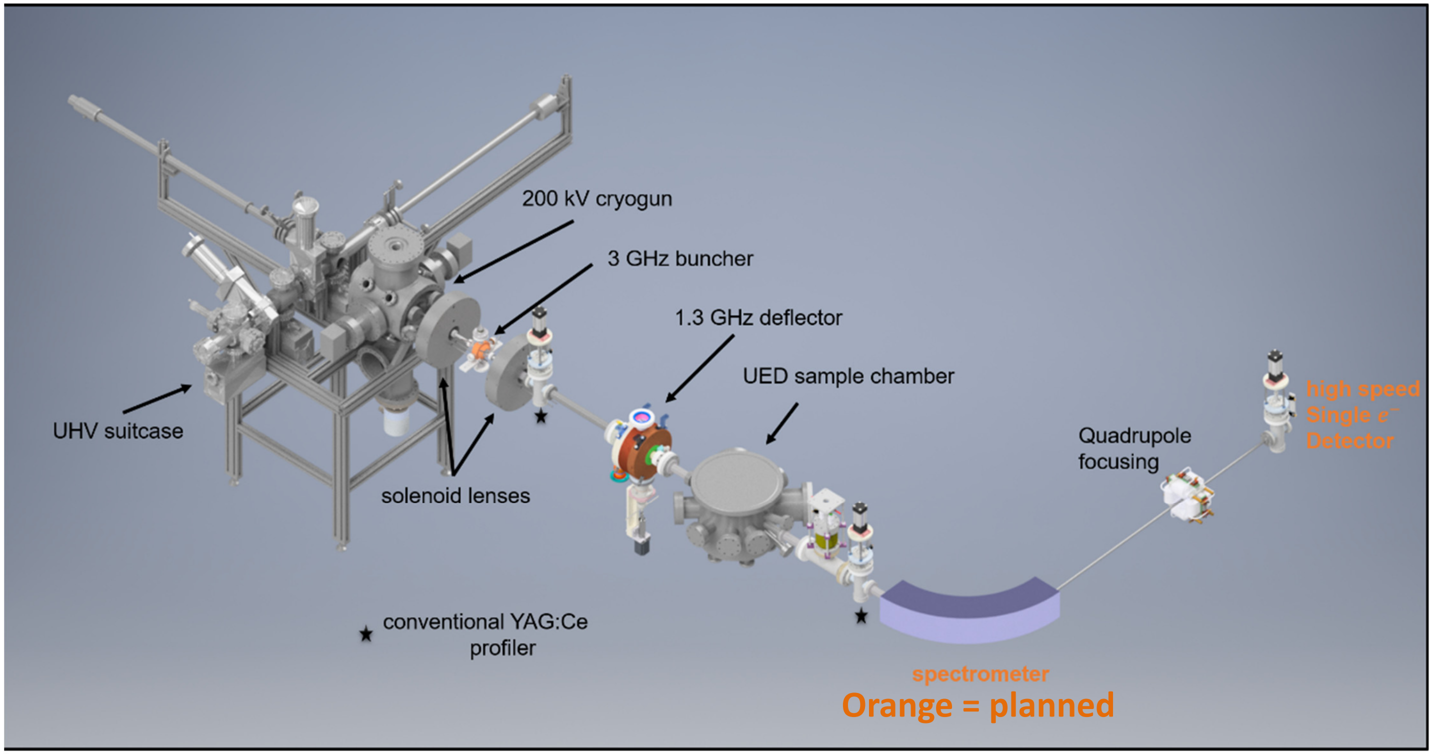
Cornell Cryogun Design



Cathode Cooled to ~40 K. Inverted insulator design *a la* Jlab.

Cornell Cryogun

- What will the cold gun do? A new UED and photoemission physics beamline
  - Physics of high brightness beams at small spatial (< nm) and temporal scales (100 fs and below).



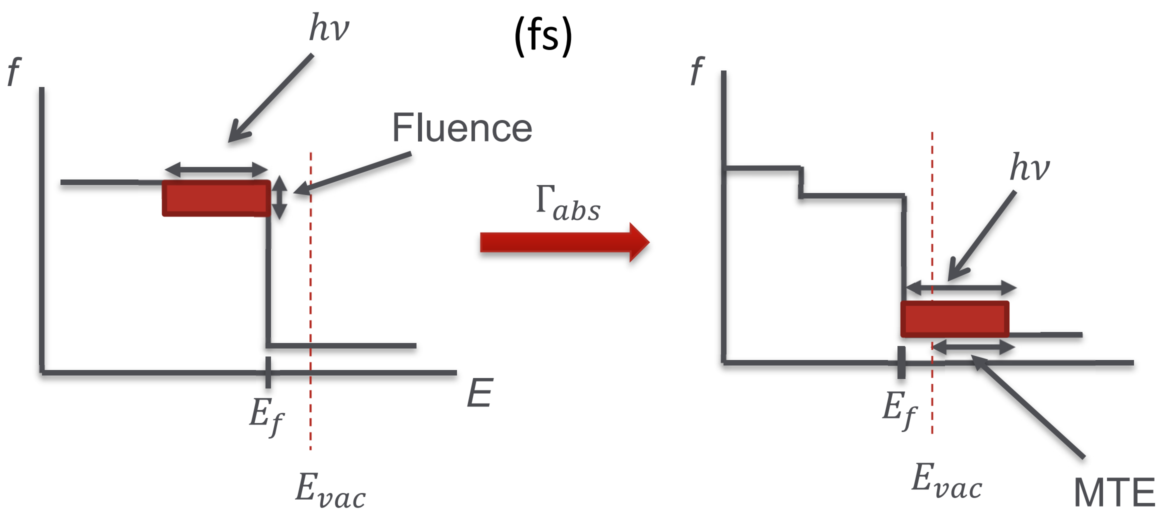
  - Short pulses and low QE? The beamline will hence also study photoemission physics at *high laser intensity*.

Driving the cathode with intense lasers

- Low QE necessitates the use of high fluence lasers.
- At high fluences (mJ/cm^2), the idea of “equilibrium photoemission” breaks down.
- Must think about photoemission as dynamic: the laser modifies the occupation of states in the material:

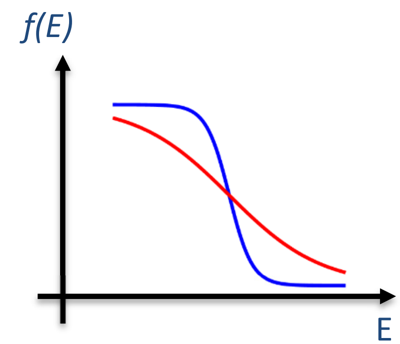
(Multiphoton) Photoemission

(fs)



Ultrafast Heating

(ps)



e-e scattering -> thermalize
e-phonon scattering -> cool kT_e

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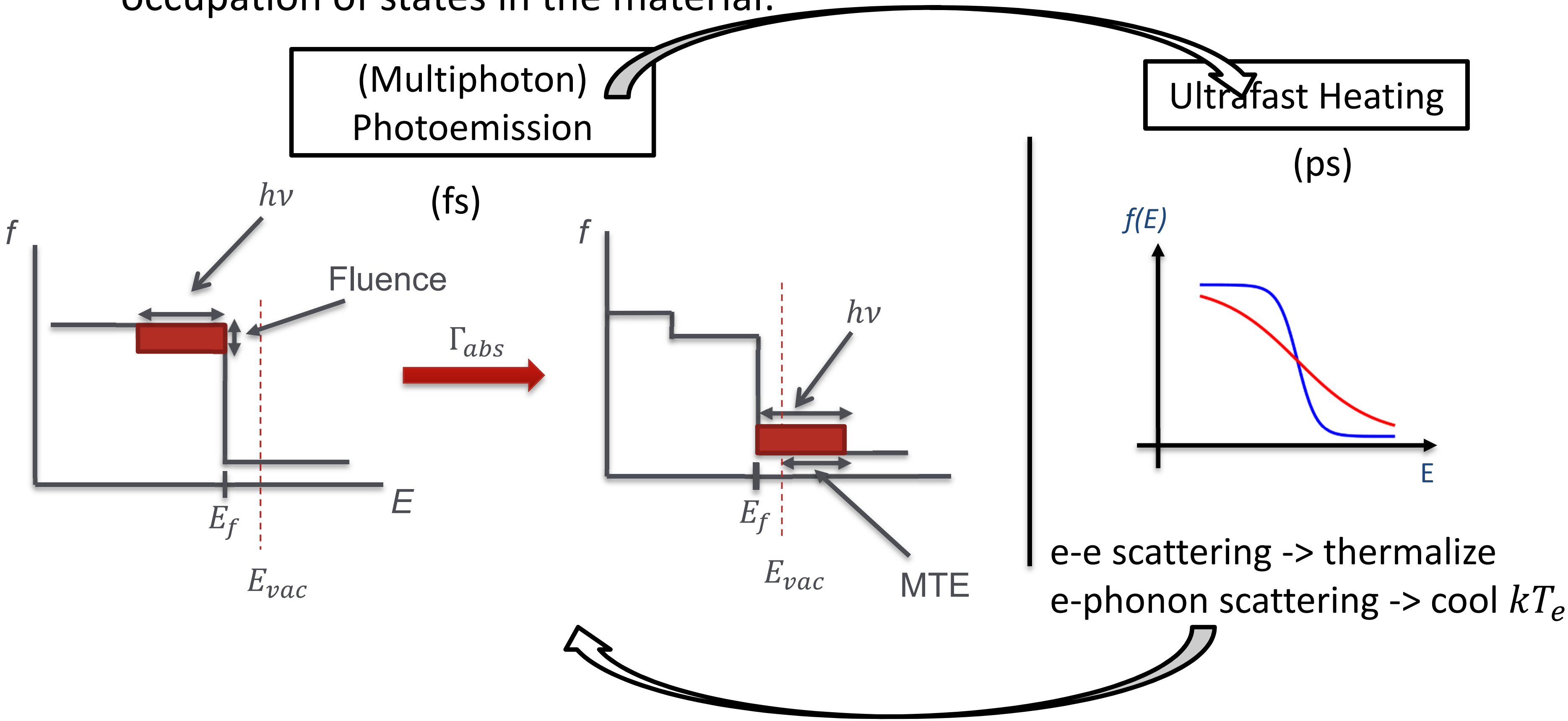
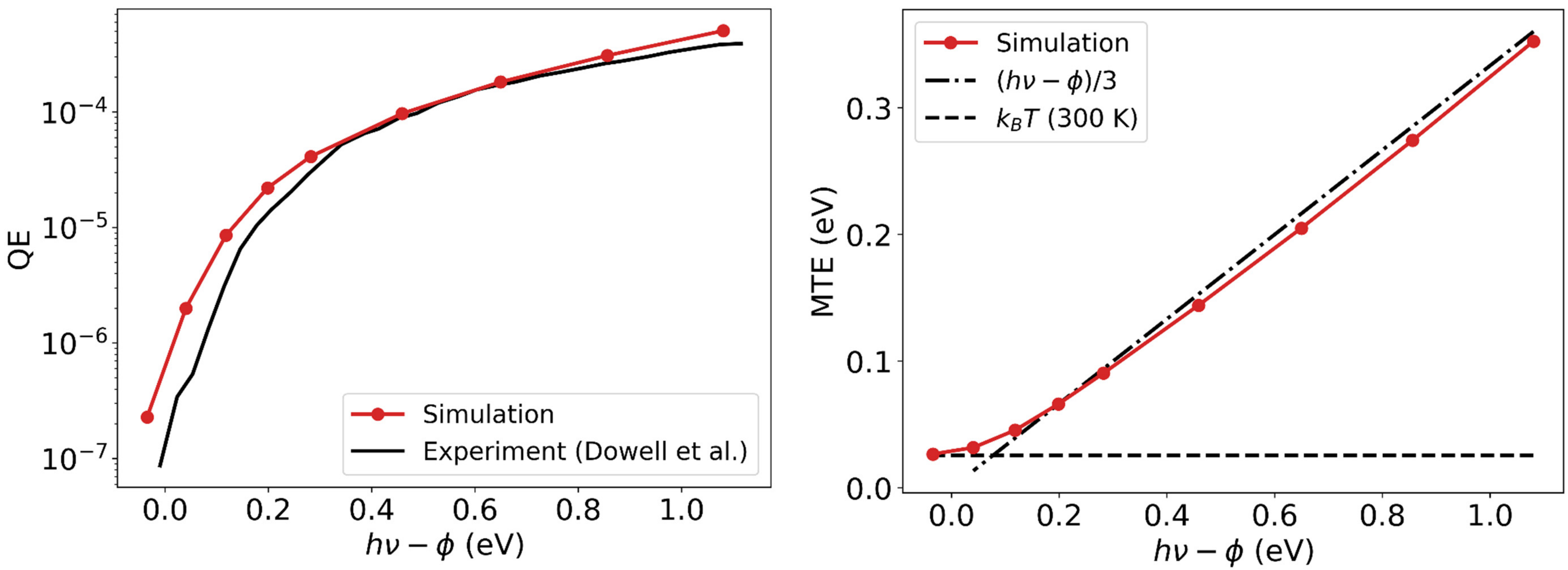


Brightness in the equilibrium regime

- Recalculate QE and kT_e from first principles with a changing f(E) using Boltzmann equation approach.
- For a 50 fs laser pulse and a Cu cathode:

Low Fluence (1e-5 mJ/cm^2)



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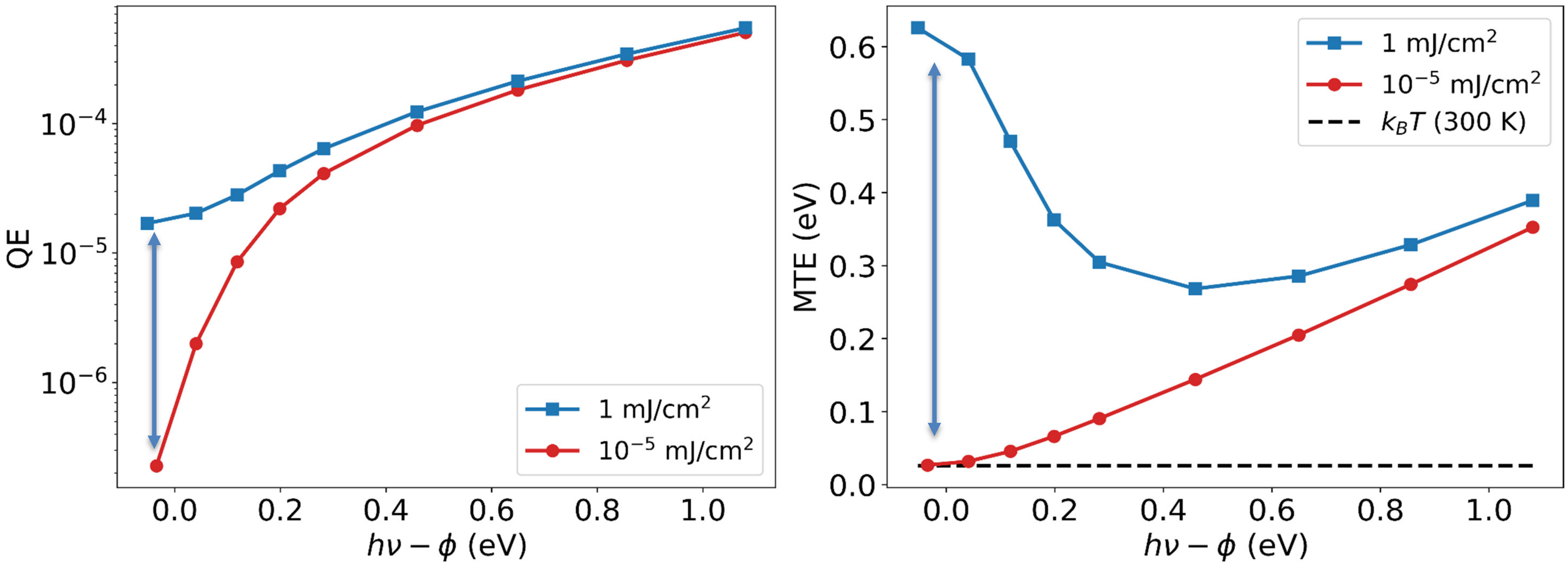

JK Bae, Journal of Applied Physics **124**, 244903 (2018)

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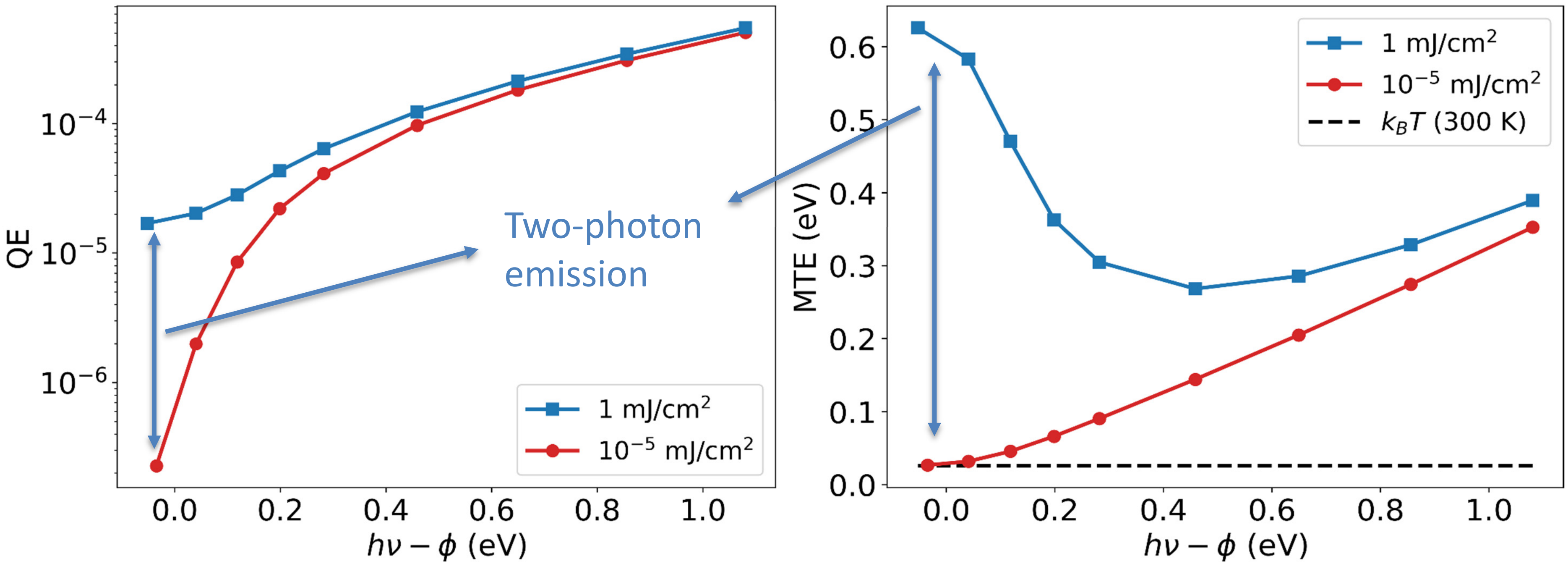
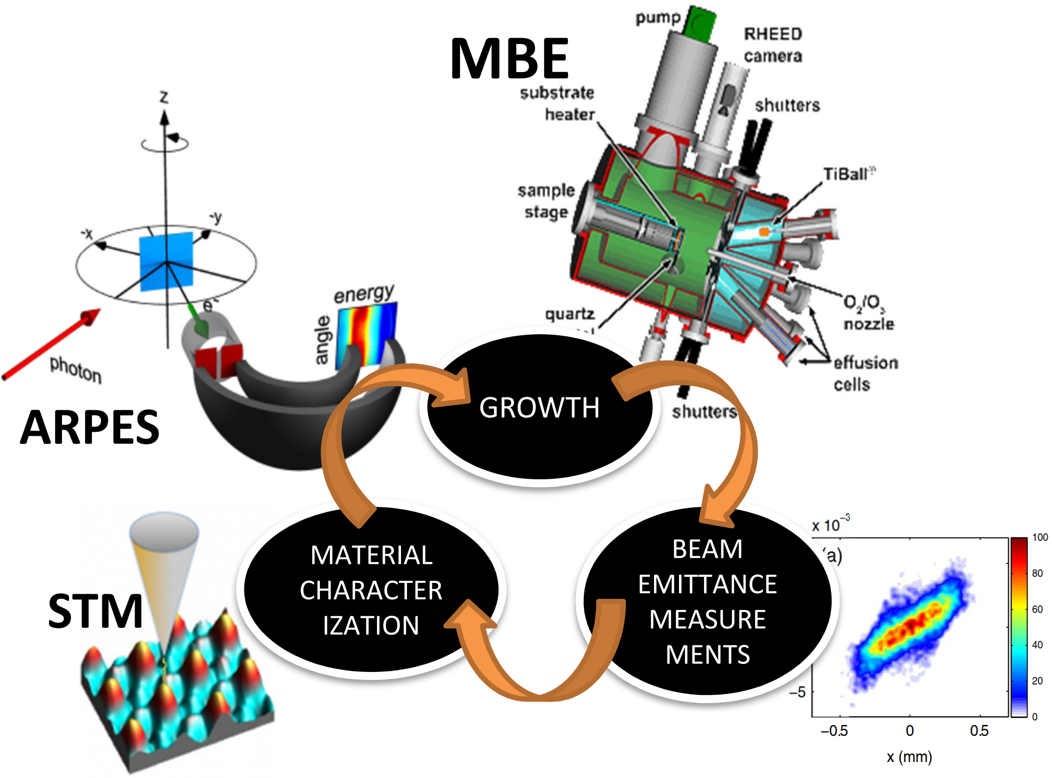


JK Bae, Journal of Applied Physics **124**, 244903 (2018)

Novel Materials discovery: "Close the Loop"

Explore new photocathode materials…like a material scientist!

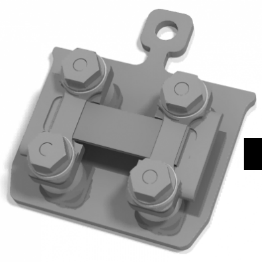


- Goals:
  - Control of the photocathode physical & chemical properties
  - Ordered materials: grown in e.g. MBE, measured in ARPES (band structure), STM (surface properties), XPS (composition)…
- Solution:
  - Universal sample holder and manipulation system **integrated with a high field cryocooled DC gun.**
  - UHV transfer with vacuum suitcase

Cryogenic TE meter: dedicated beam emittance measurement system

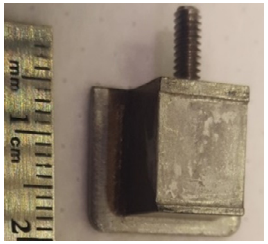
NEW INSTRUMENT

- 1 meV resolution
- Cryogenic (down to LHe)
- Realistic operating condition
  - Gradient similar to injector (>10 MV/m)
  - SRF injector operating T
- Compatible with sample holders:



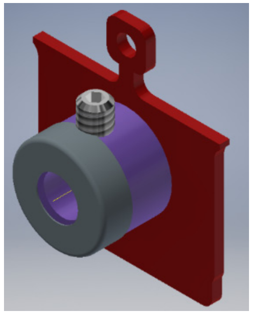
Standard Omicron

+



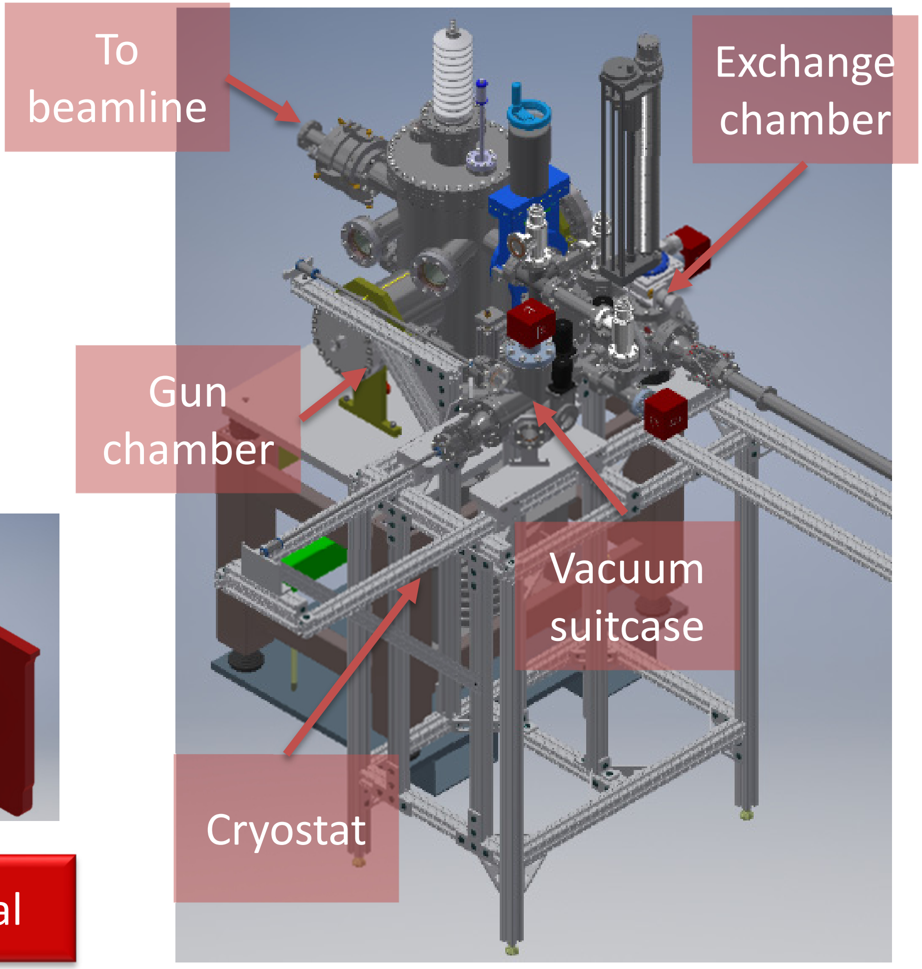
MBE/ARPES

=



Universal

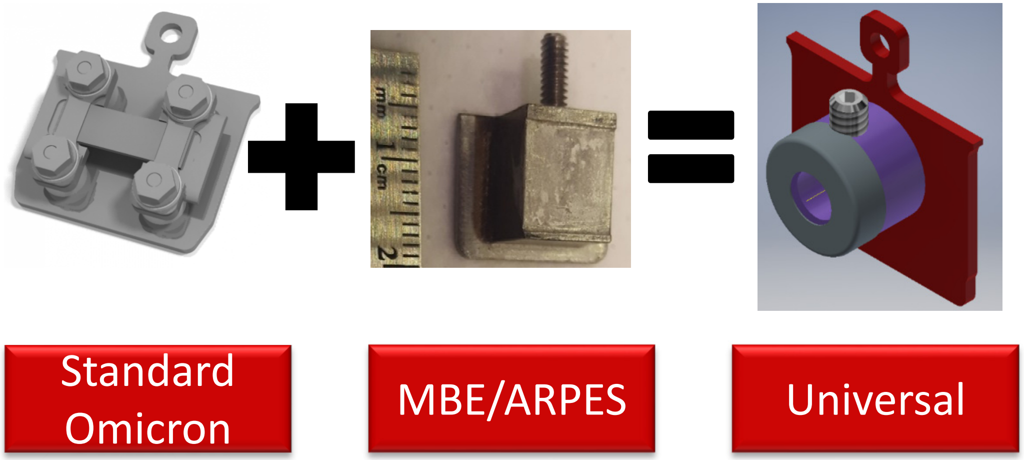
TE meter with exchange chamber and vacuum suitcase



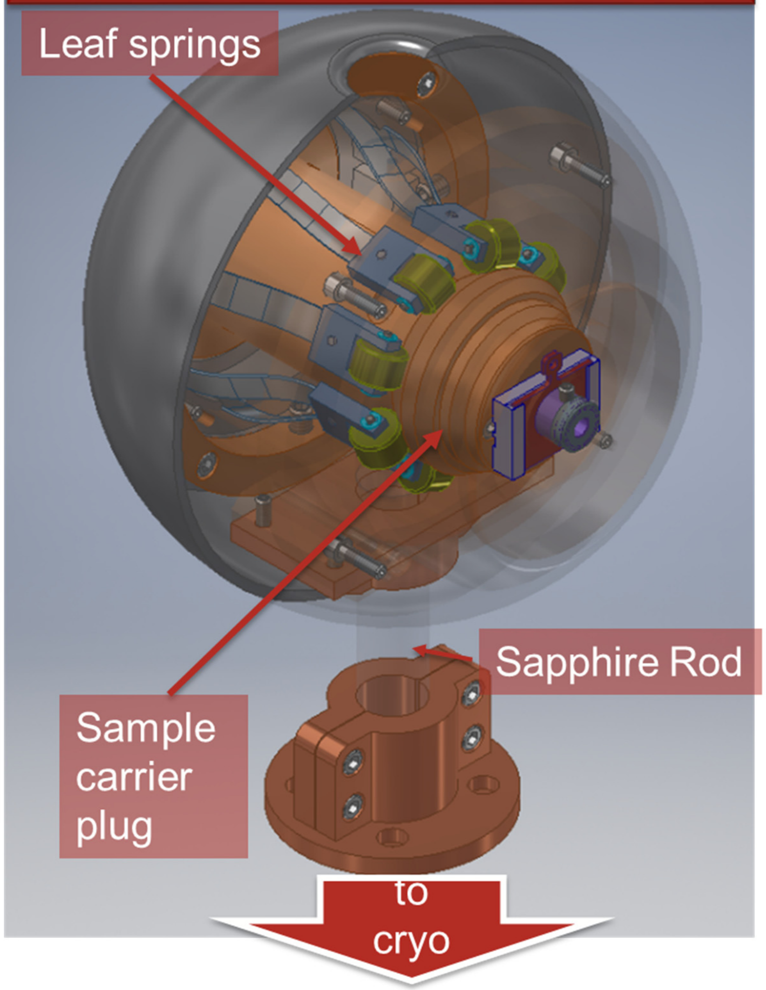
Cryogenic Emittance Measurement Gun

NEW INSTRUMENT under construction

- 1 meV transverse energyresolution
- Cryogenic (down to LHe)
- Realistic operating condition
  - Gradient similar to injector (>10 MV/m)
  - SRF injector operating T
- Compatible with sample holders:

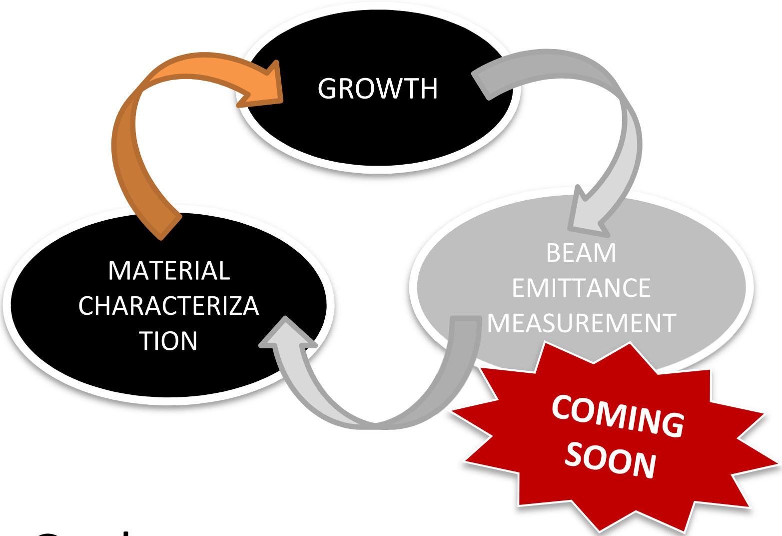


Inspired to Cornell Cryo-gun design



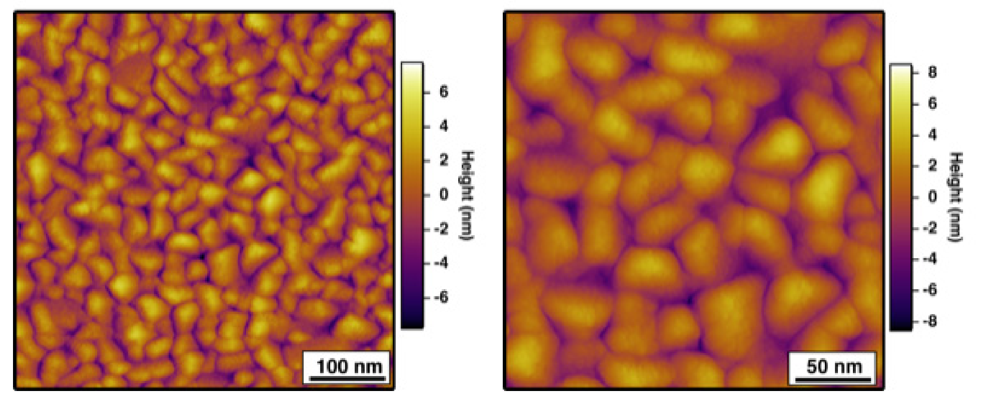
H. Lee et al. RSI 89 (8), 083303 (2018)

Surface science for photocathodes: Cs_3Sb case study



- Goals:
  - minimize the roughness of Cs_3Sb samples to reduce intrinsic emittance
  - Ensure chemical homogeneity of the samples (Cs^{1+}, Sb^{3-}, Cs^0, Sb^{5+}…)
  - Study the influence of substrate materials on the samples’ morphology

Transfer to Surface Science laboratory via vacuum suitcase

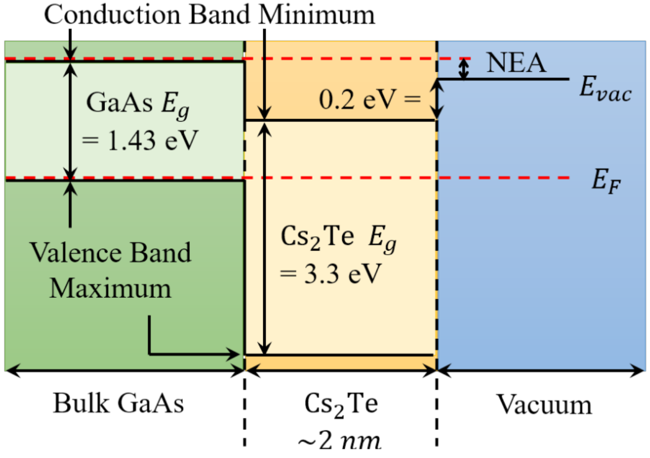


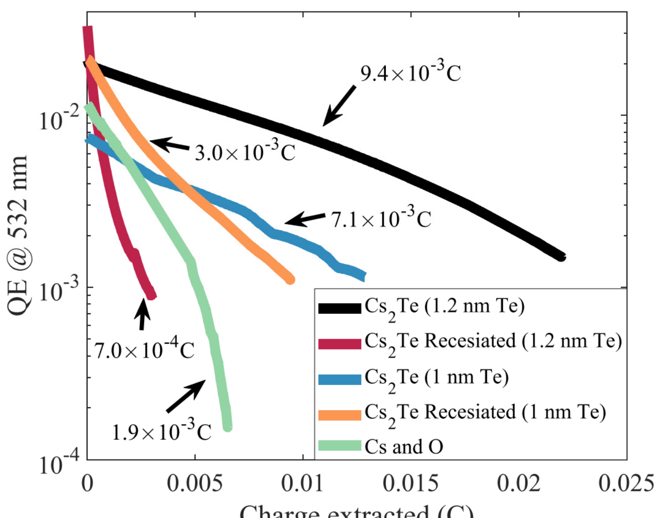
STM images of Cs_3Sb samples grown on H-terminated Si

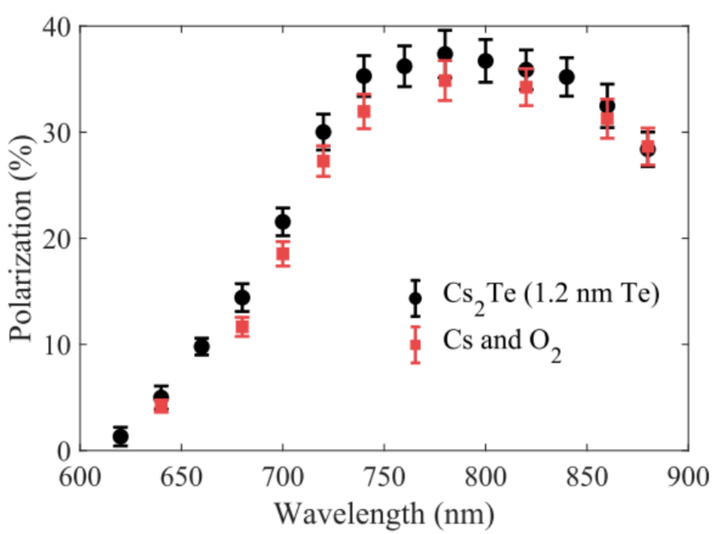
Long Lifetime Polarized photocathodes

- Emittance is not the only figure of merit for photocathodes…
- Nuclear physics and HEP machines of the future may need **high polarization and long lifetime**
- Cesiated GaAs remains the state of the art in high QE polarized photocathodes.
- Charge lifetime is still a challenging issue!

- Recently, GaAs coated with Cs_2Te has shown to yield negative electron affinity activation. Cs_2Te is also known to be a robust photocathode! Does a protective coating harm the polarization?
- For a ~2 nm layer—the answer is no!
- Does it actually protect? 5x longer charge lifetime as compared to activation with just Cs and O.



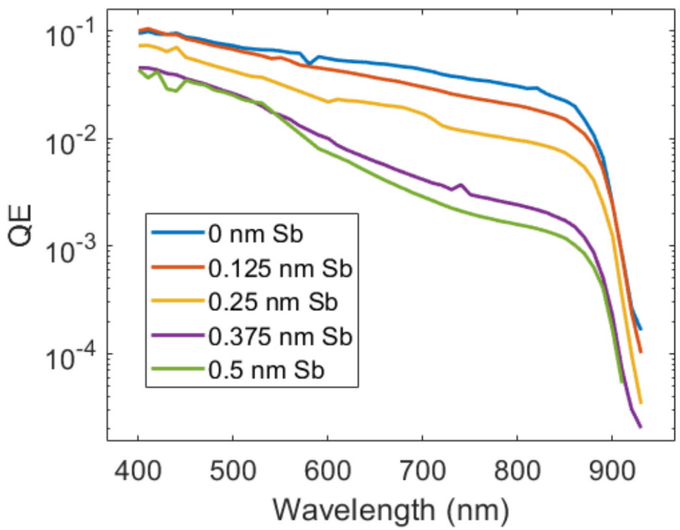


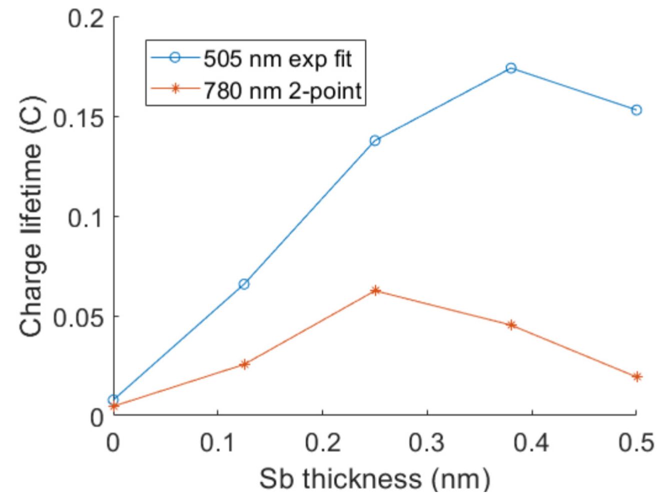


Bae, et al. Applied Physics Letters 112.15 (2018): 154101.

Cs_3Sb activation layer

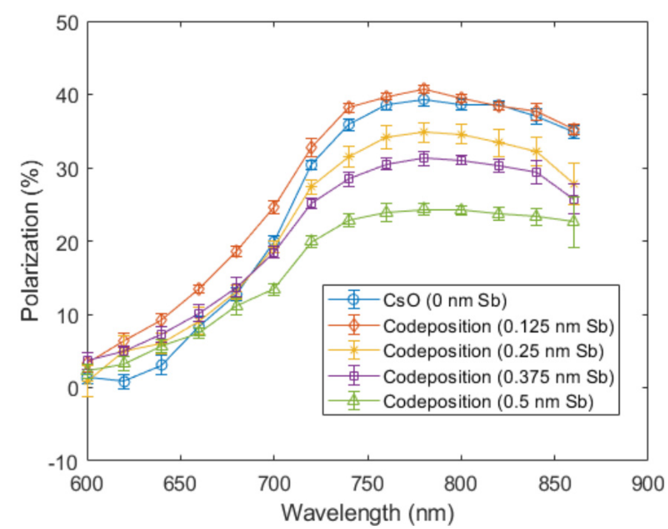
- **Exciting new result :** GaAs NEA activation with Cs_3Sb**!**





Lifetime improved beyond that achieved with CsTe coating, with high QE in the IR!

Tradeoff between thickness, lifetime And polarization—studies are ongoing.

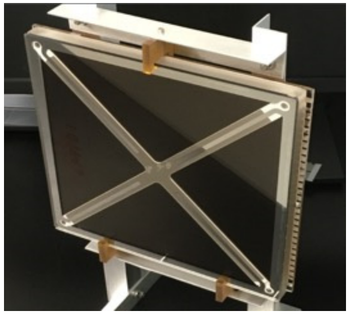


New avenue for our lab: photodetectors

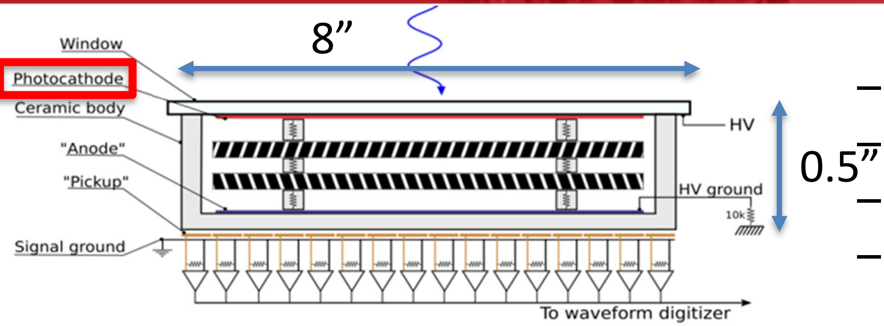
Photocathodes for photodetector applications

- "And now for something completely different!"
- We have spent years studying the growth and optimization of alkali antimonide photocathodes…
- Beyond just accelerators, there are other HEP relevant applications of high QE photocathodes: *photodetectors.*

Photocathode for LAPPD™



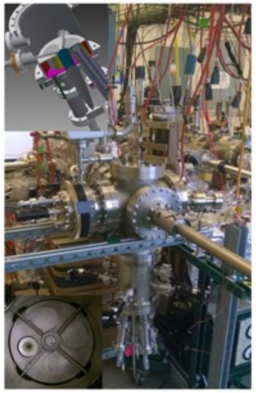
Incom LAPPD™



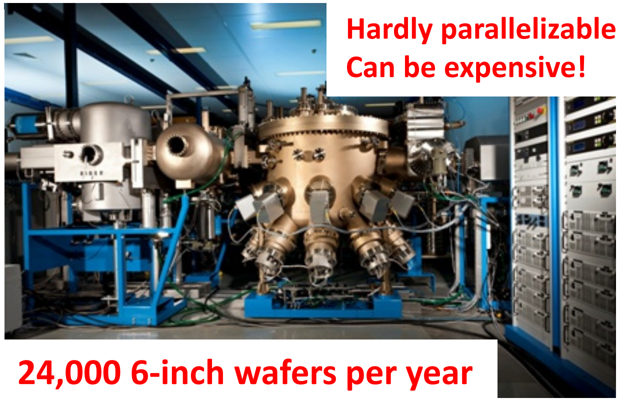
- Transmission mode high peak QE;
- Uniformity over large area;
- Infrared response (bonus);
- Scalable for mass production;

1- All UHV process (Growth and UHV seal)

UHV growth chamber based on effusion cell filled with elemental materials is part of CU photocathode lab.



From R&D to mass production



Hardly parallelizable!
Can be expensive!

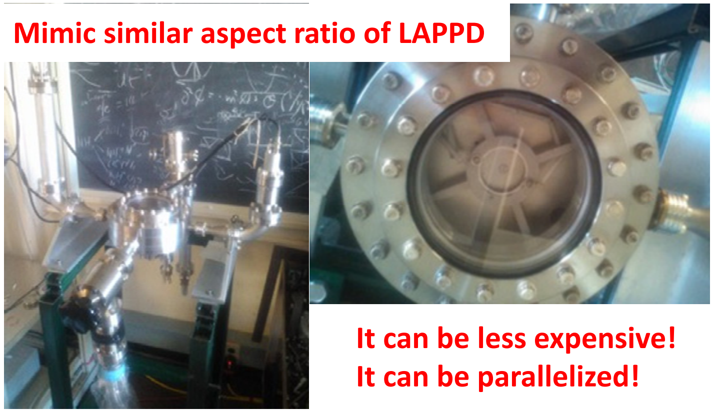
24,000 6-inch wafers per year

2- In situ process (Only final reaction with alkali in UHV sealed device)

Can implement a PMT like growth process with the LAPPD geometry?

From mass production to R&D

Mimic similar aspect ratio of LAPPD

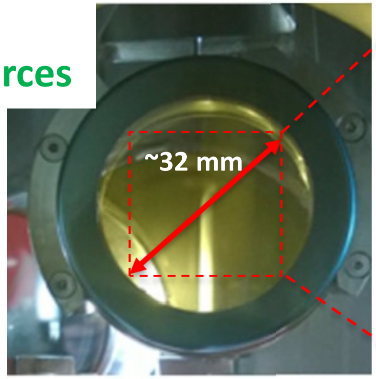


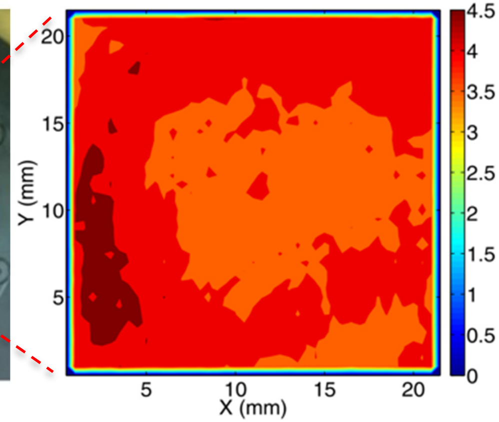
It can be less expensive!
It can be parallelized!

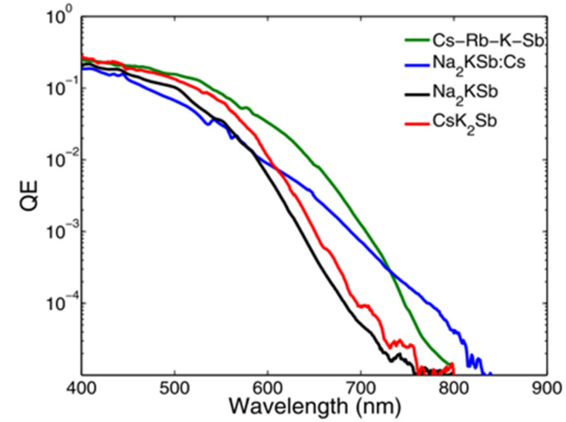
1.5” Transmission-mode photocathodes

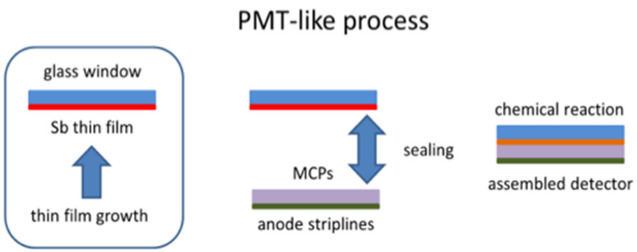
All UHV process
MBE-like elemental sources

Transmission mode!
Uniform QE!
High peak QE!
Infrared response!

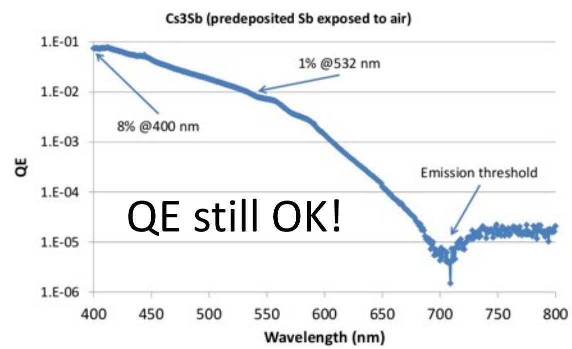




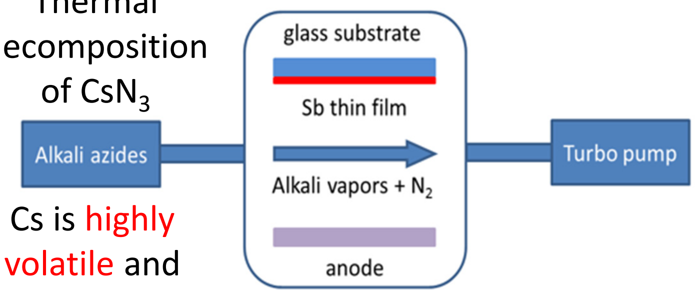




Involves air exposure of the Sb to open air to perform the seal of the tile

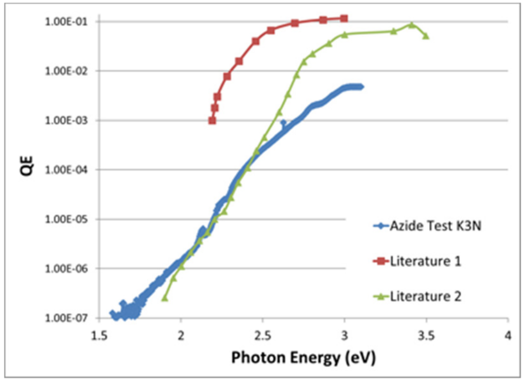


Thermal decomposition of CsN_3



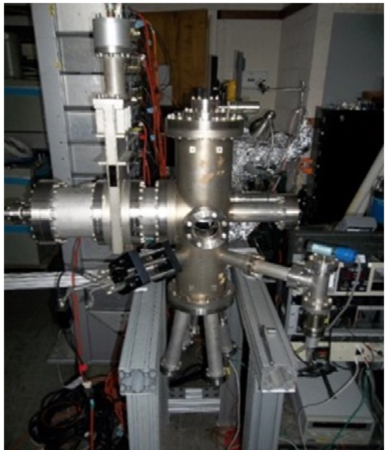
Cs is highly volatile and Cs_3Sb has already high QE

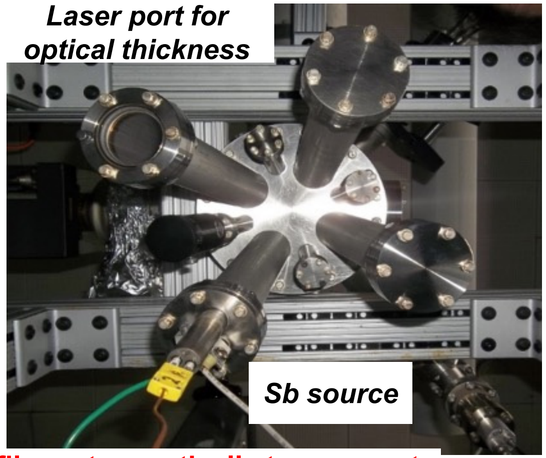
High purity CsN_3 is discontinued worldwide and we used KN_3 instead.

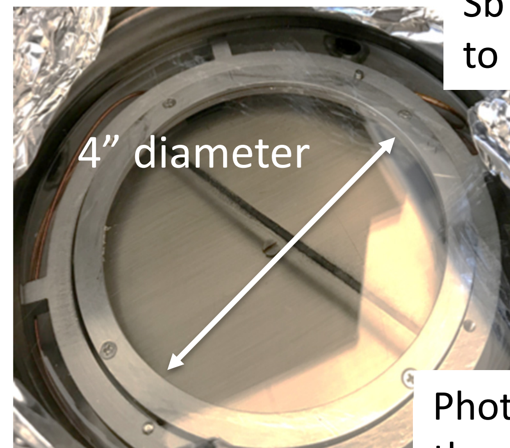


4” Transmission-mode photocathodes

New unique setup where we can study the growth process in a non line of sight conditions like the one imposed by the geometrical constraint of LAPPD™ like detectors.



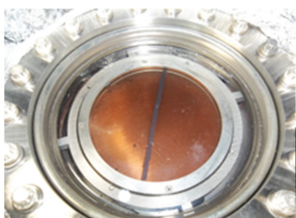




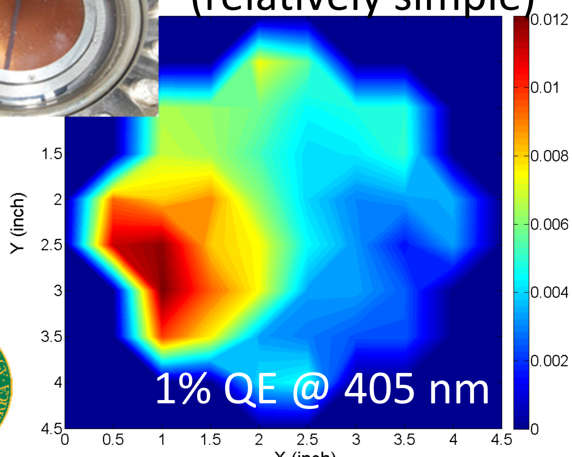
Sb thickness used to optimize QE

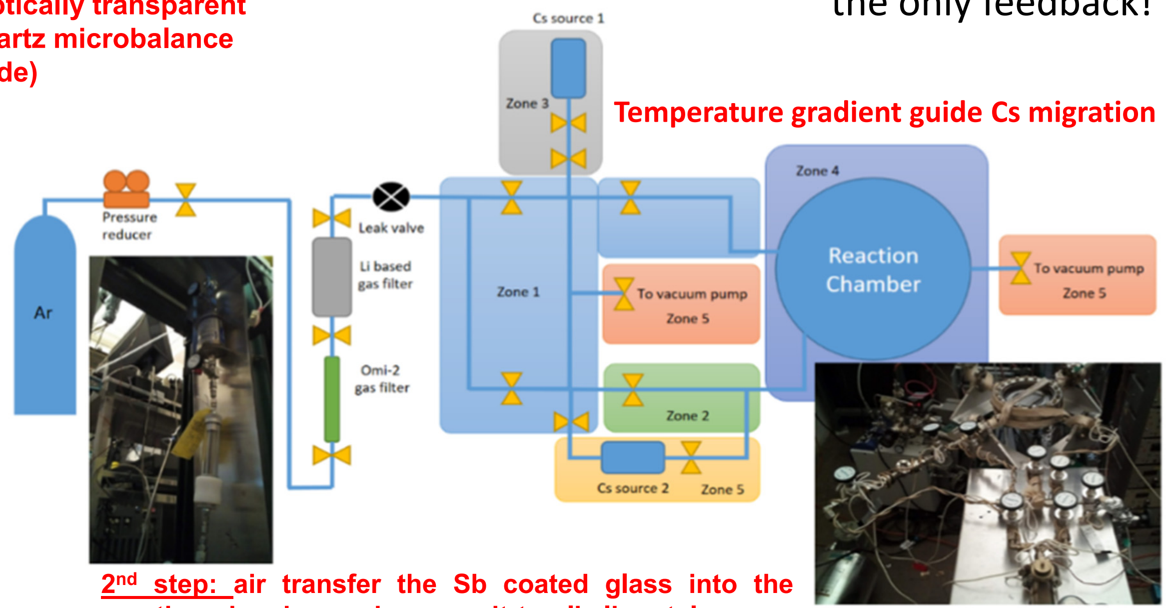
Photocurrent still is the only feedback!

1st step: grow an Sb film onto a optically transparent substrate using effusion cells (quartz microbalance and optical thickness used as guide)



Cesium antimonide (relatively simple)





2nd step: air transfer the Sb coated glass into the reaction chamber and expose it to alkali metal vapors in a non-line-of-sight geometrical configuration.

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Acknowledgements

- The whole photocathode team: I. Bazarov, L. Cultrera, A. Galdi, J. Bae, C. Duncan, W. Li, C. Pierce, F. Ikponmwen, T. Moore, M. Hines, W. DeBenedetti, J. Balajka

- DOE and NSF for funding (DE-SC0011643, DE-SC0019122, PHY-1549132)