Summary of “Physics of Photocathodes for Photoinjectors” workshop BNL, October 3-5, 2023

Luca Cultrera

EWPPA – workshop – HZDR, September 17-19, 2024

@BrookhavenLab

Special Thanks

Local Organizing Committee

- L. Cultrera (co-Chair)
- M. Gaowei (co-Chair)
- S. Capp

Support staff

- C. Weaver
- D. Basozmen

Scientific Committee

- Luca Cultrera
- Oksana Chubenko
- Dimitre Dimitrov
- Mengjia Gaowei
- Carlos Hernandez-Garcia
- Kevin Jensen
- Siddharth Karkare
- Jared Maxson
- Nathan Moody
- Pietro Musumeci
- John Smedley
- Marcy Stutzman
- Theodore Vecchione

P3 workshop 2023, BNL

75 Registered participants

7 sessions, 37 talks

15 posters

Brookhaven National Laboratory

P3 workshop 2023, BNL

7 plenary sessions

- **Introductory session**
- **High charge - High average current**
- **Free Electron Laser (two sessions)**
- **Theory (two sessions)**
- **Novel concepts (two sessions)**
- **Ultrafast Diffraction and microscopy**
- **Spin polarized sources**

I will try to give an objective and comprehensive summary
Talks are uploaded to the following indico website
Photocathode Physics for Photoinjectors Workshop (3-October 5, 2023) · Indico (bnl.gov)

Introductory session

EWPAA 2022 Highlights

D. Sertore
INFN Milan – LASA

Lee Jones (STFC, DL), On behalf of the EWPAA Organizing Committee

Electron Sources for Particle Accelerators

YINE SUN
Advanced Photon Source
Argonne National Lab.

Oct. 3, 2023
Photocathode Physics for Photoinjectors Workshop
Stony Brook, New York

ERL in European Strategy for Particle Accelerator

Accelerator R&D Roadmap and it's impact on photocathode research

- New accelerator roadmap emphasise interest to further development of Energy Recovery Linacs (ERL) as high efficiency sustainable accelerator facilities.
- High average current, in 100 mA range, electron injectors are one of the most critical components of ERLs and additional efforts should be concentrated on further development of the injectors.
- Major efforts should be concentrated on the following:
  - Optimisation technology of existing photocathode materials
  - Development new photocathode materials which could operate with existing laser system
  - Design photocathode plug which may be compatible with different types of the guns
- Development of laser systems which would allow for delivery required current with UV photocathodes
- Development of gun technologies which would allow for providing beams compatible with existing accelerator structures without excessive bunching schemes. Potential to reach this goal have.
  - High field QWR SRF gun
  - High field QWR NCRF gun
  - Elliptical cavity SRF gun
- There is no operational injector which can demonstrate 100 mA of polarised current: Limited by photocathode lifetime
- Potential to deliver this current (if GaAs lifetime by activation with Cs-alkali metal layer is successful),
  - DC photocathode guns
  - SRF photocathode guns

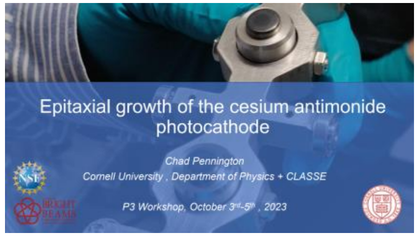
Boris Militsyn
STFC Daresbury Laboratory, UK

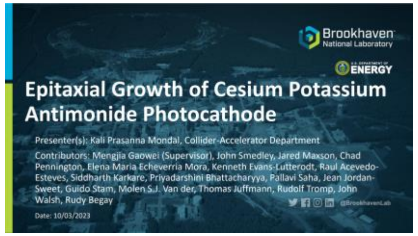
April 2023: $e^{\pm}$ Source Roadmap Working Group Report

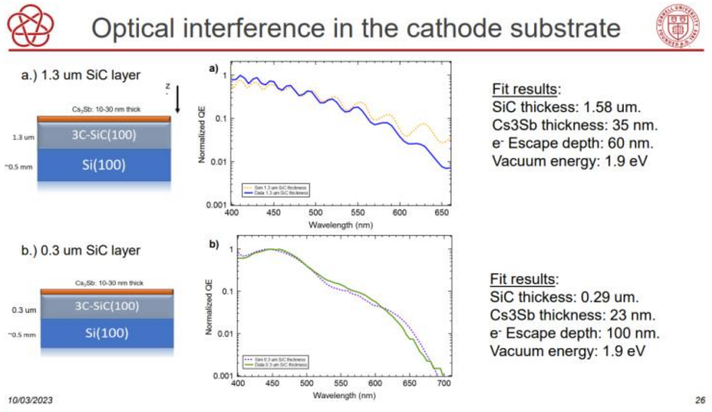
https://indico.fnal.gov/event/59123/

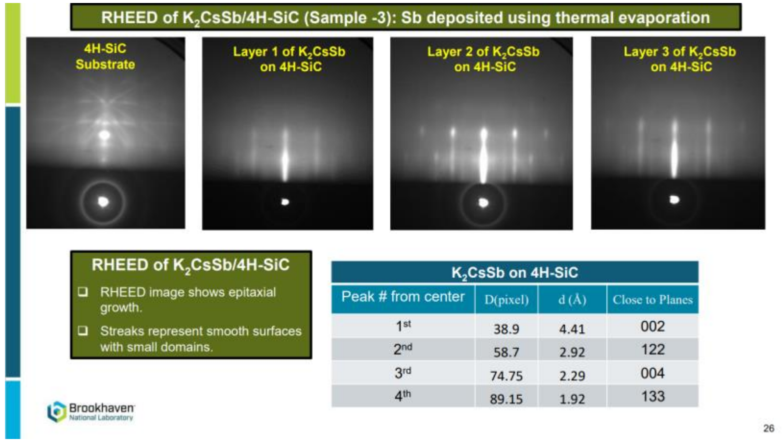
Year	Near-term (<5 years)	Mid-term (5~10 years)	Long-term (10~20 years)
e^- Cathode	Reliable high-P GaAs supply chain	Cryogenic temperatures and very high fields operation	
	Robust photocathodes in DC guns (20mA pol. and 100 mA unpol.)		
	Photocathodes with 1% QE and 30 meV MTEs	Photocathodes with 1% QE and 5 meV MTEs	
	Continue to explore new and promising photocathodes (robust surfaces, nano-structures, higher QE and polarization)		
e^- Gun	DC gun beam ~1-10 mA polarized	10^{-14} Torr vacuum for long GaAs lifetime	DC gun beam 10~20 mA polarized
	NCRF: cryo gun at 250 MV/m; x-band gun, CW and Low Frequency rf gun		
	Polarized GaAs in an SRF photogun	SCRF gun 50 MV/m	
e^- Injector	Control laser profile, limit nonlinear SC induced emittance growth: beer can (mid); elliptical (far)		
	NCRF, SRF accelerating cavities: fully RF symmetrized fields to eliminate emittance growth to 10% (near), 1%(mid), 0.1%(far)		
		Partition phase space: RFBT+EEX for damping ring free (mid), linear LPS (long)	
	High Charge Drive Bunch Trains: charge-balanced, equal energy bunches duration 5-25 nsec.		
e^+ polarized	SC undulators	Collider-class polarized e+ source	
	Compton-based sources - high flux circularly polarized gamma-rays R&D		
	Bremmstrahlung polarized positron source development		
e^+ unpolarized	Targets for high intensity		
	Capture and acceleration sections		
	Compact sources for accelerator and ultrafast science (also polarized)		
	10^{-14} Torr vacuum for long GaAs lifetime	Routine 10's mA GaAs beams	

High Charge / High Average Current



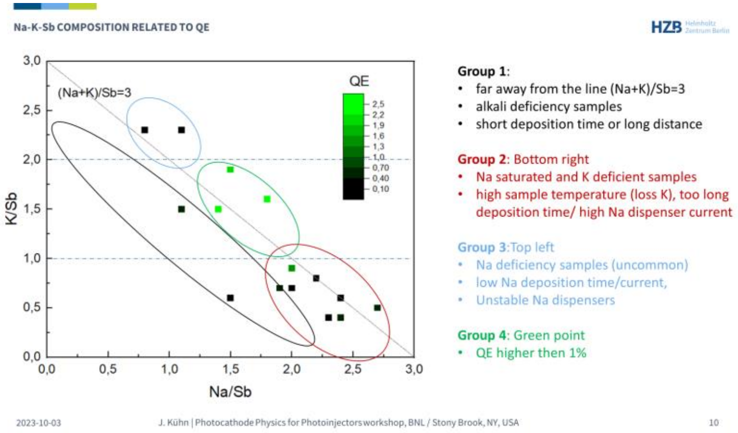


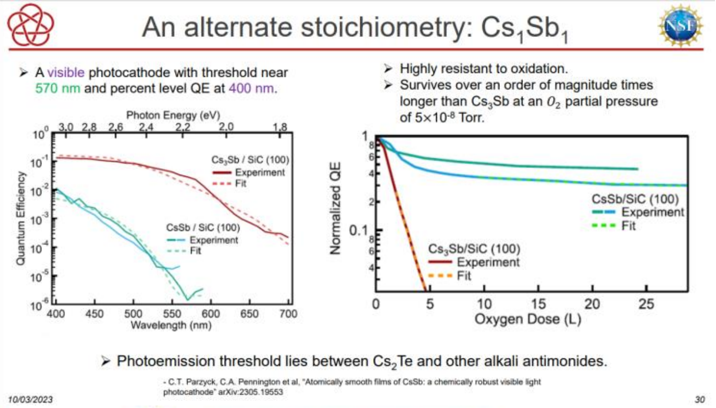


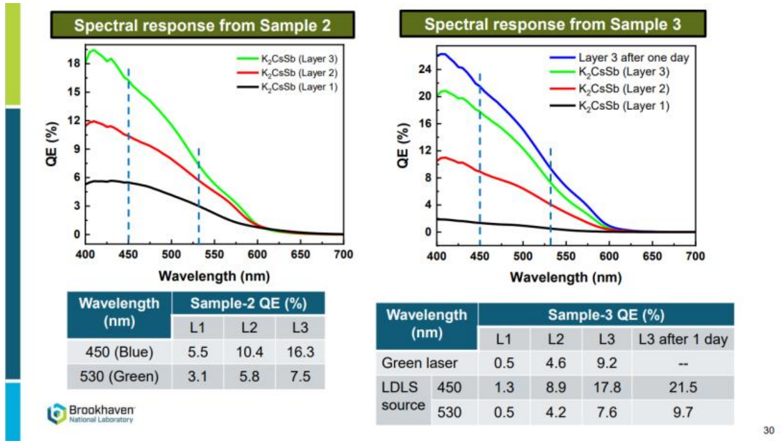


K_2CsSb on 4H-SiC

Peak # from center	D(pixel)	d (Å)	Close to Planes
1st	38.9	4.41	002
2nd	58.7	2.92	122
3rd	74.75	2.29	004
4th	89.15	1.92	133

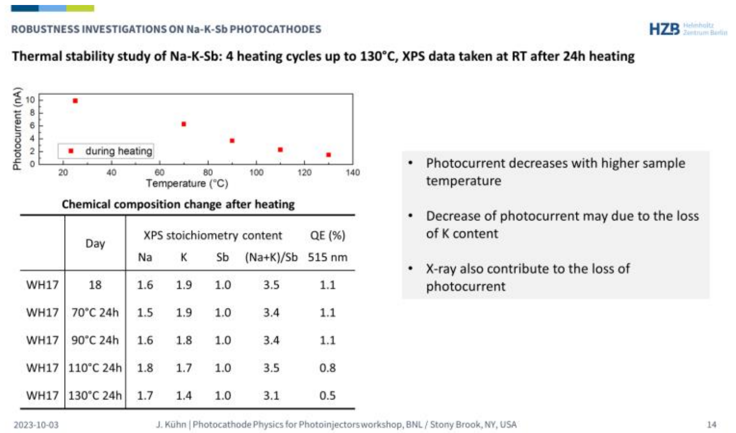






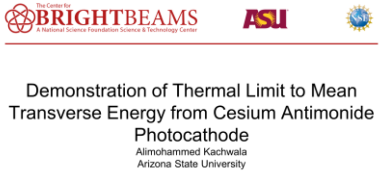
Wavelength (nm)	Sample-2 QE (%)		
	L1	L2	L3
450 (Blue)	5.5	10.4	16.3
530 (Green)	3.1	5.8	7.5

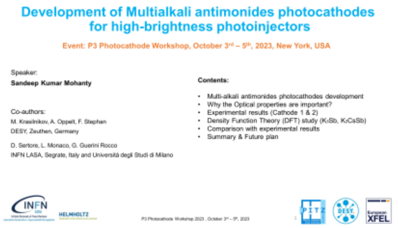
Wavelength (nm)		Sample-3 QE (%)			
		L1	L2	L3	L3 after 1 day
Green laser		0.5	4.6	9.2	--
LDLS source	450	1.3	8.9	17.8	21.5
	530	0.5	4.2	7.6	9.7

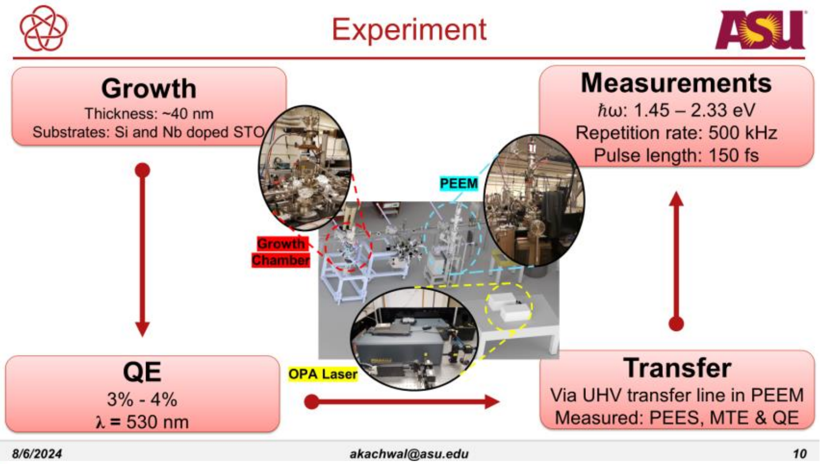


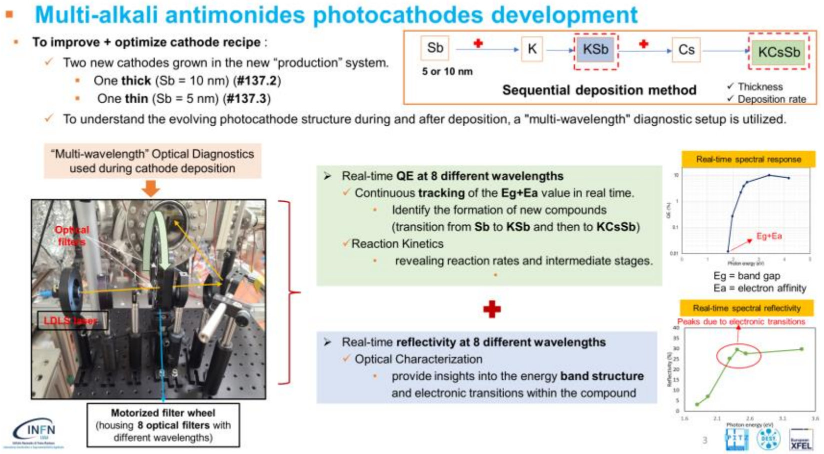
	Day	XPS stoichiometry content				QE (%)
		Na	K	Sb	(Na+K)/Sb	515 nm
WH17	18	1.6	1.9	1.0	3.5	1.1
WH17	70°C 24h	1.5	1.9	1.0	3.4	1.1
WH17	90°C 24h	1.6	1.8	1.0	3.4	1.1
WH17	110°C 24h	1.8	1.7	1.0	3.5	0.8
WH17	130°C 24h	1.7	1.4	1.0	3.1	0.5

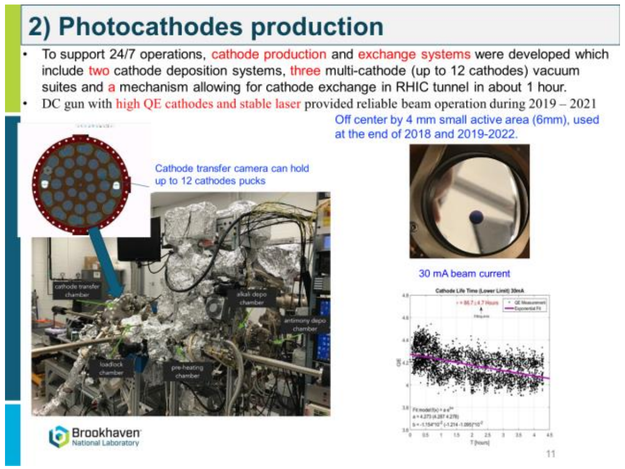
High Charge / High Average Current

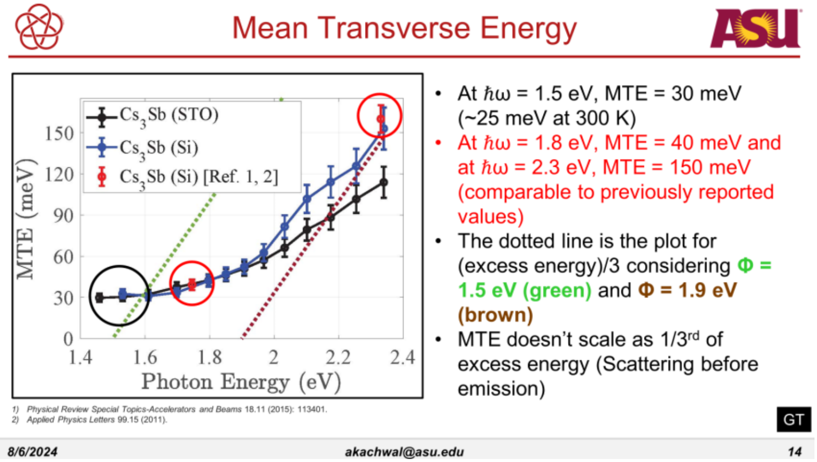


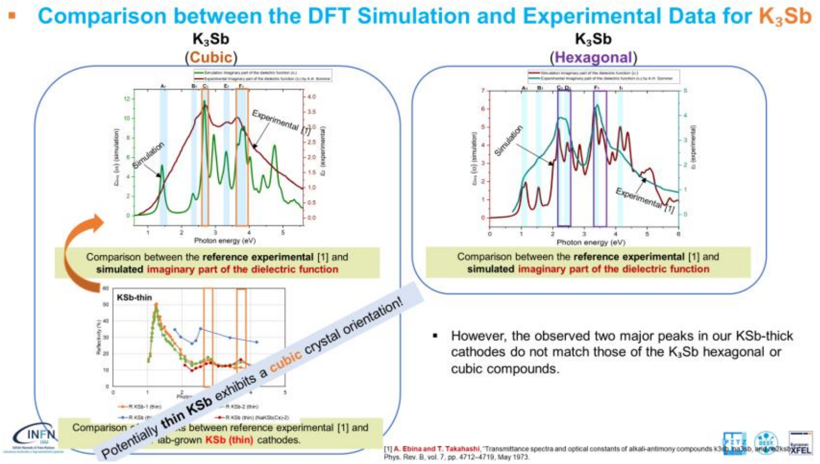


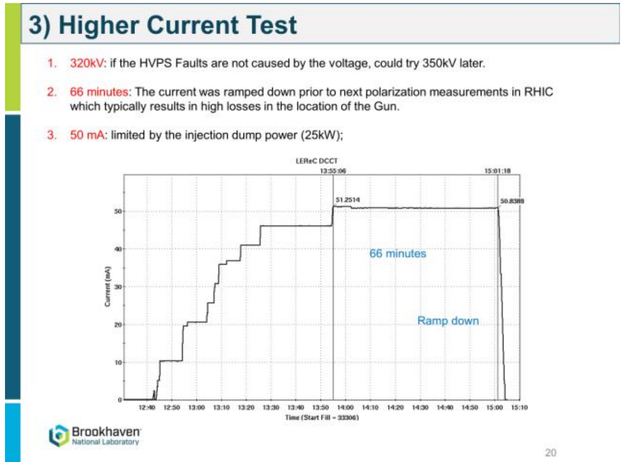




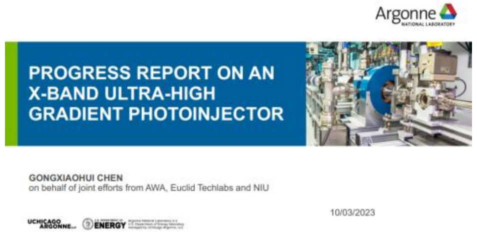


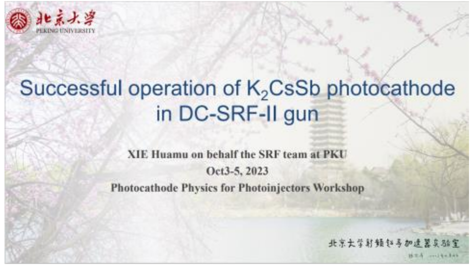


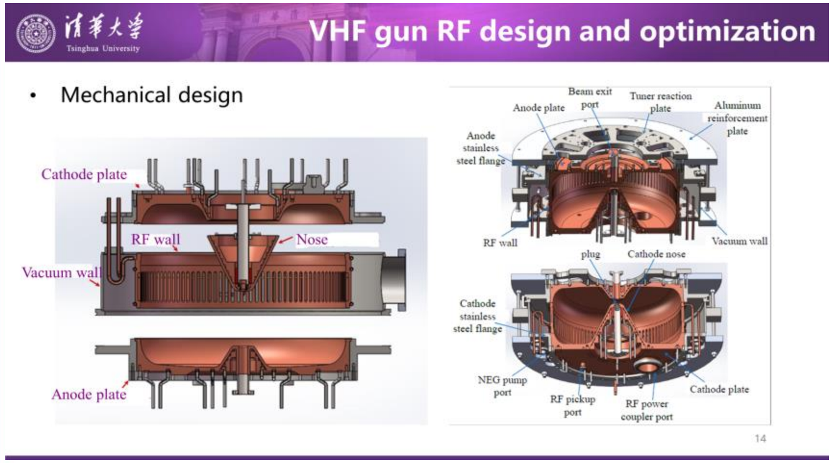


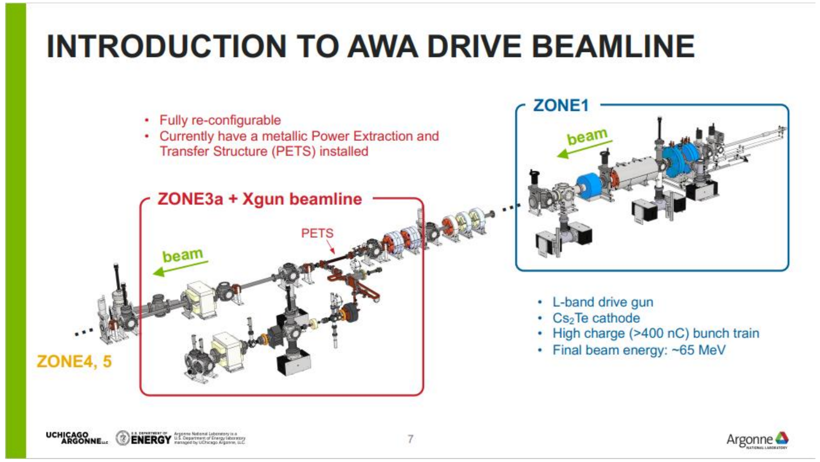


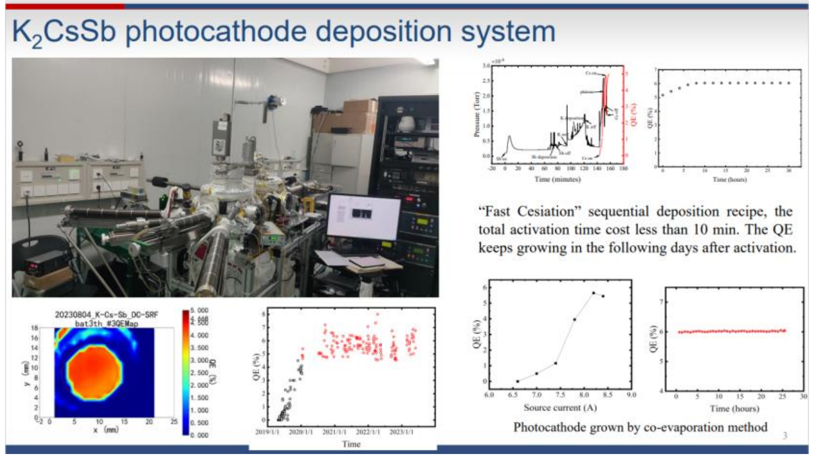
Free Electron laser

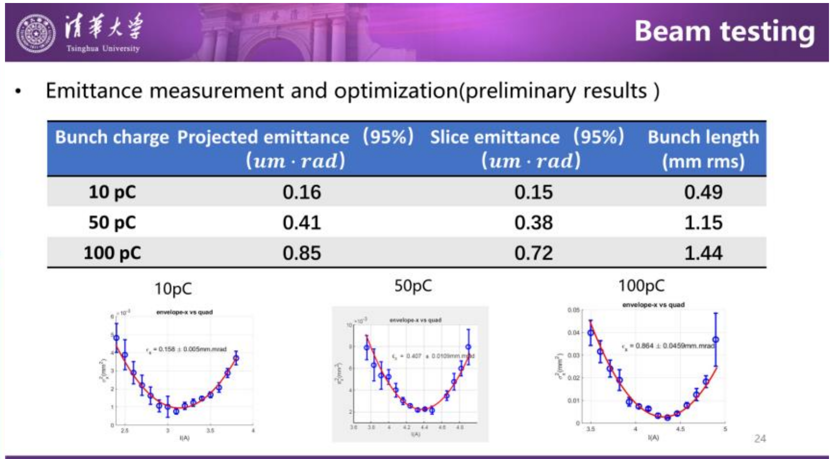




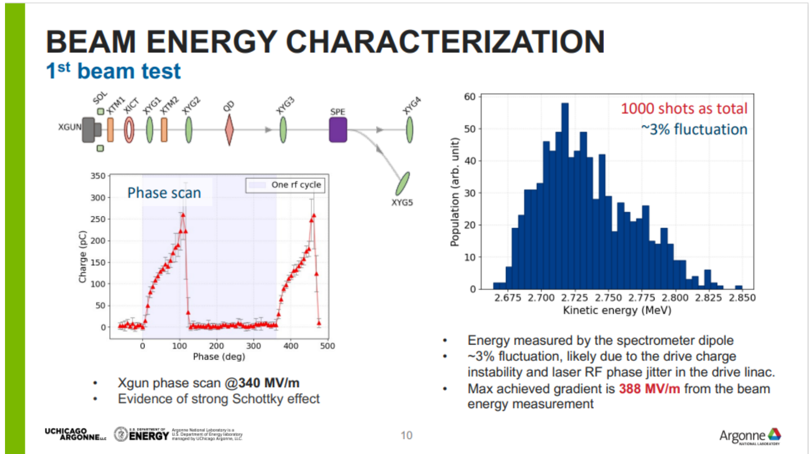


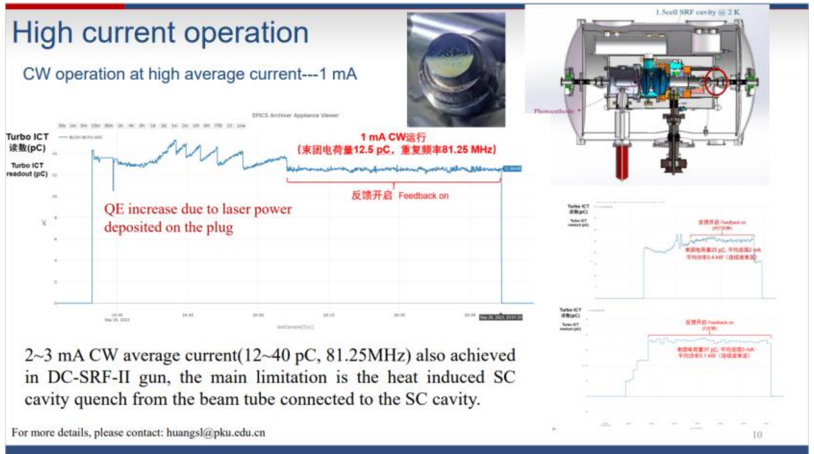




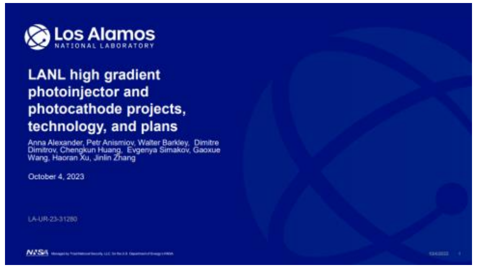


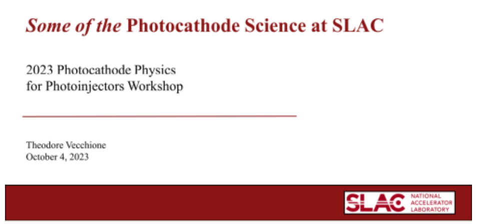
Bunch charge	Projected emittance (95%) $(um \cdot rad)$	Slice emittance (95%) $(um \cdot rad)$	Bunch length (mm rms)
10 pC	0.16	0.15	0.49
50 pC	0.41	0.38	1.15
100 pC	0.85	0.72	1.44

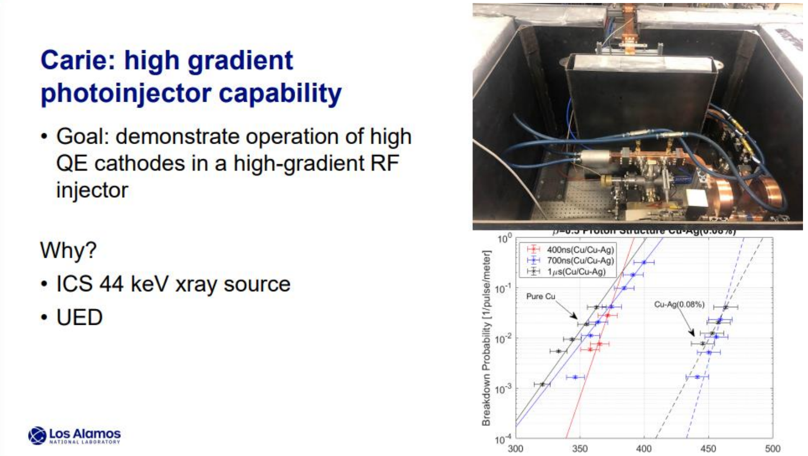


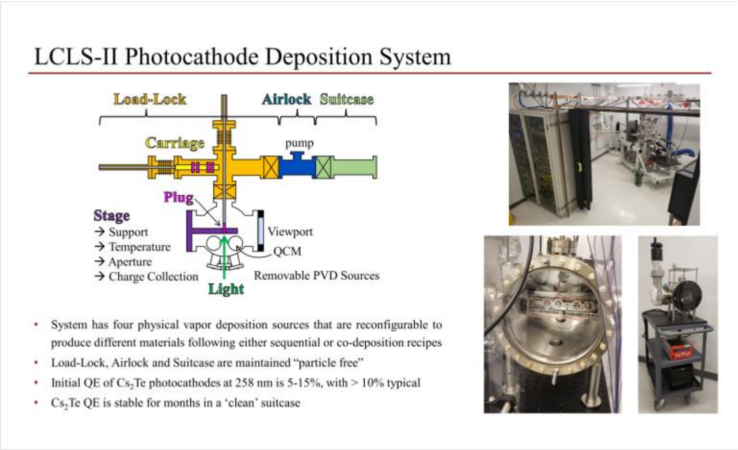


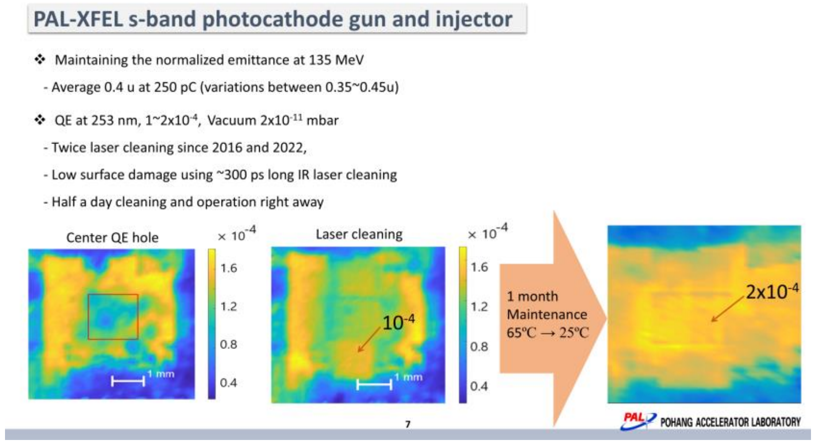
Free Electron laser

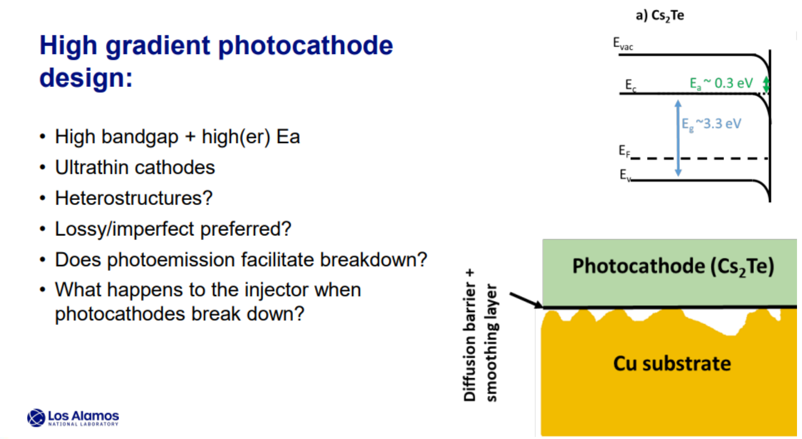


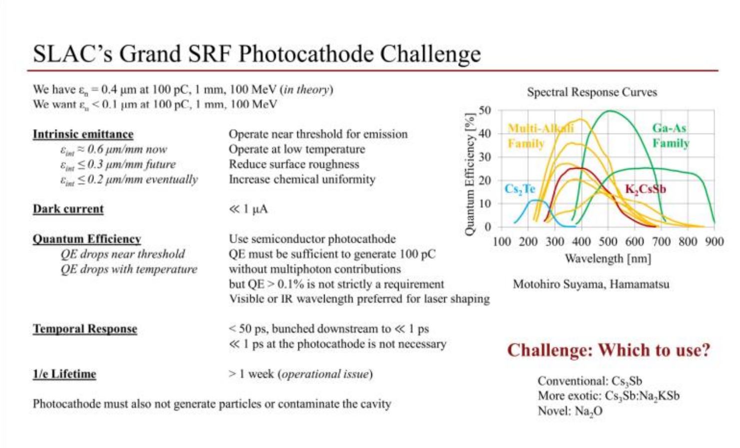


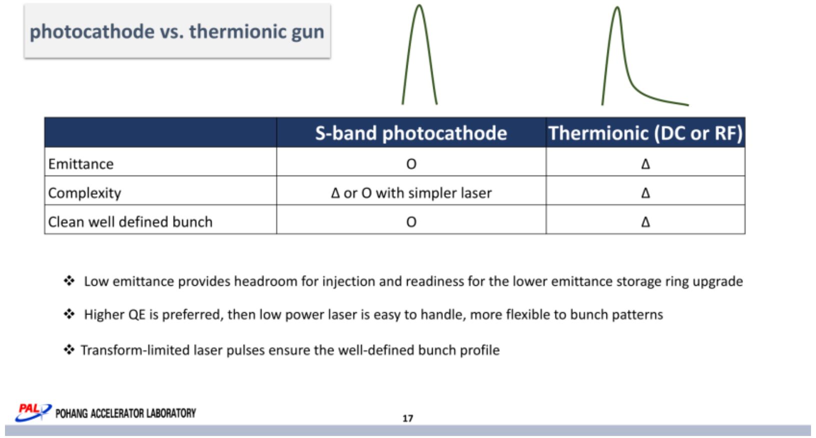




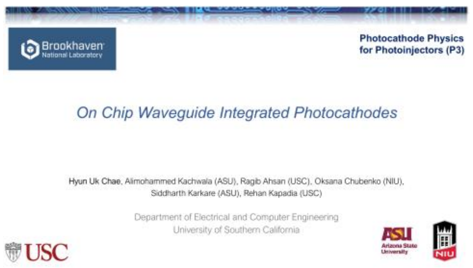


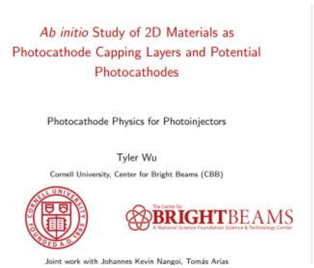


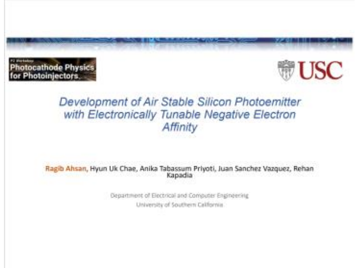


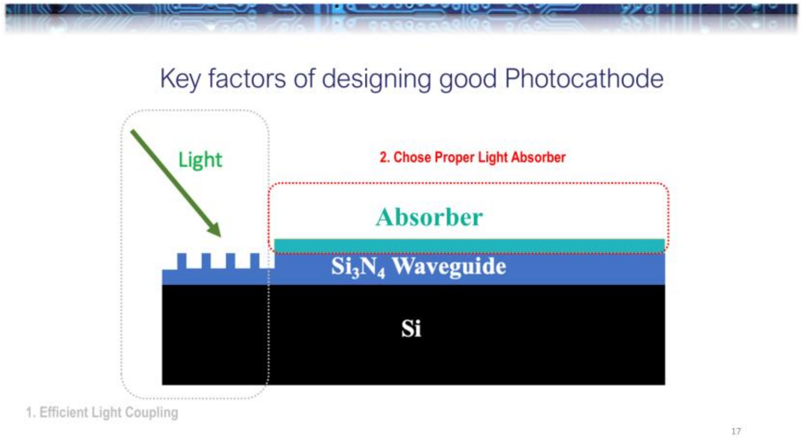


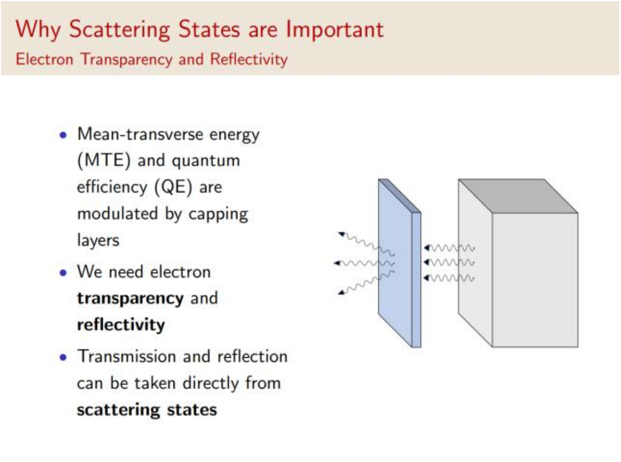
Novel concepts

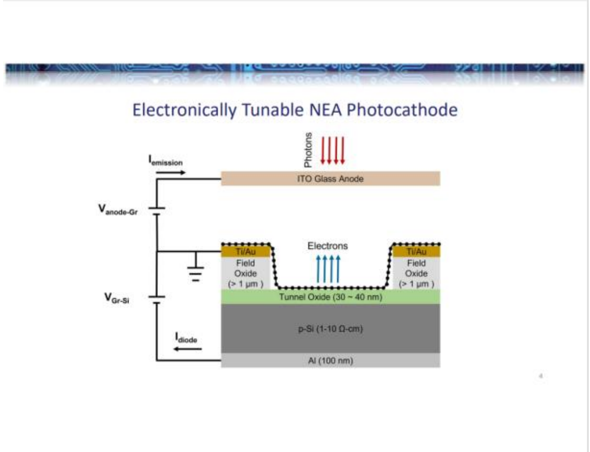


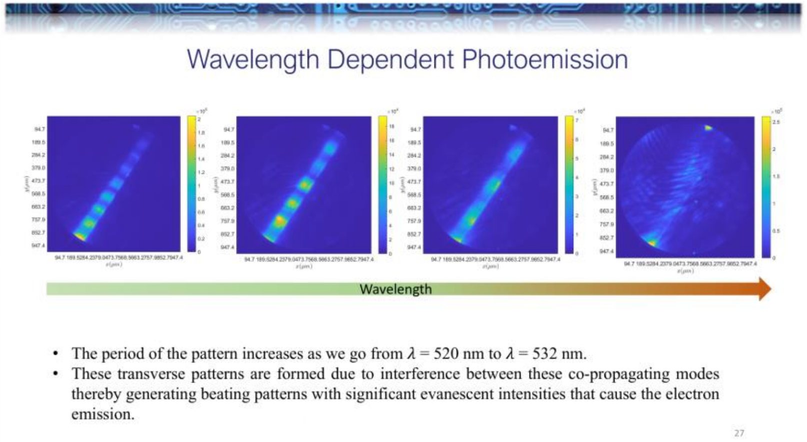


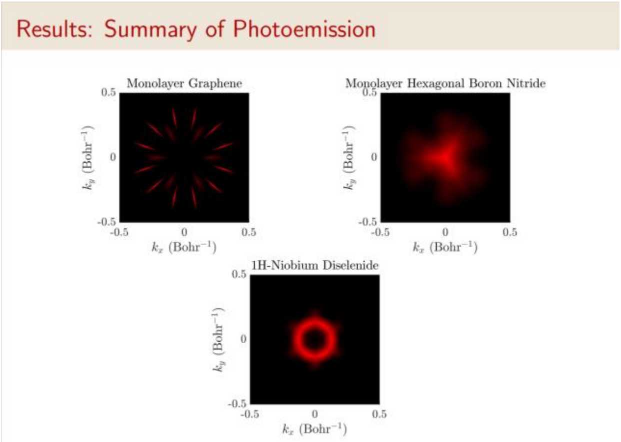


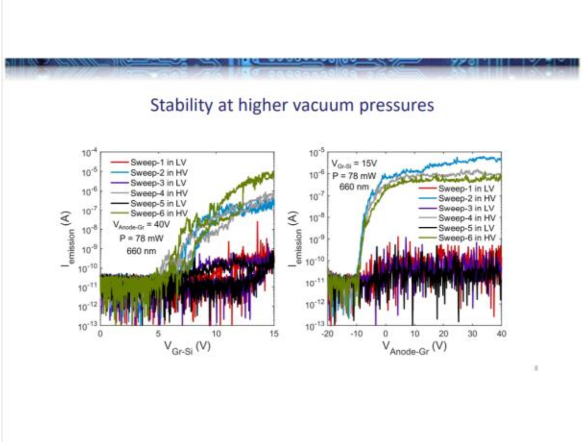




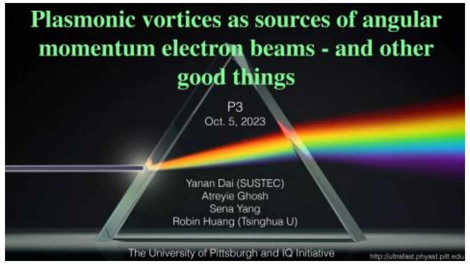


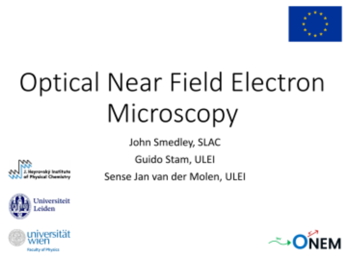


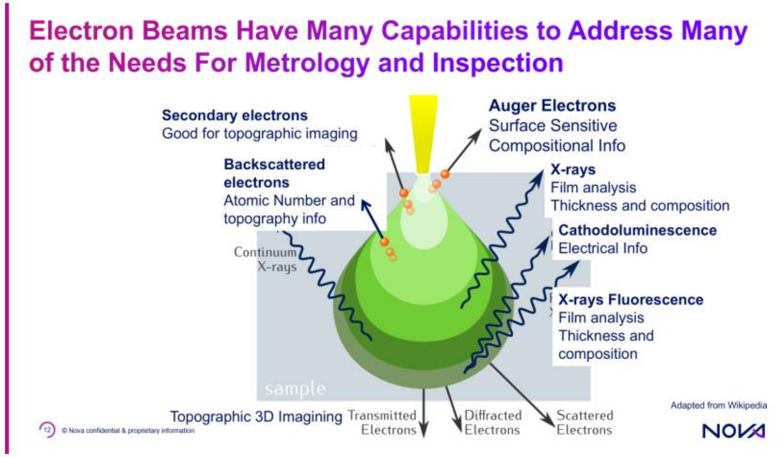


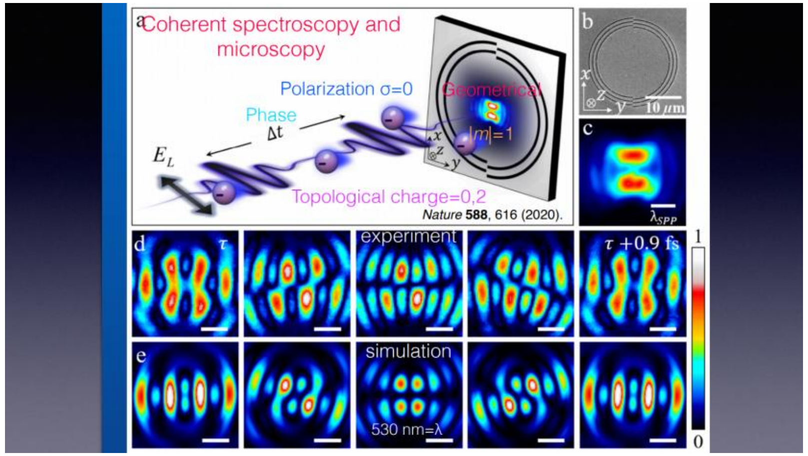


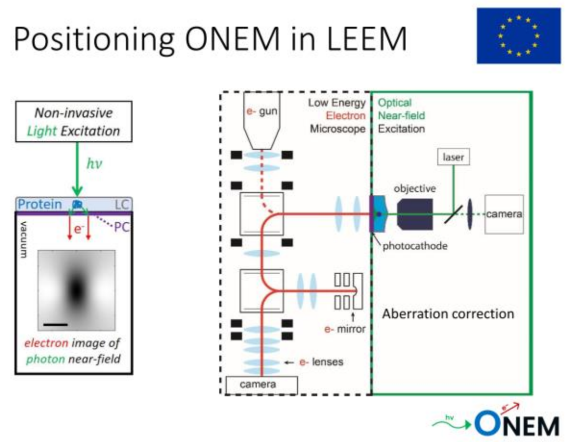
Novel concepts

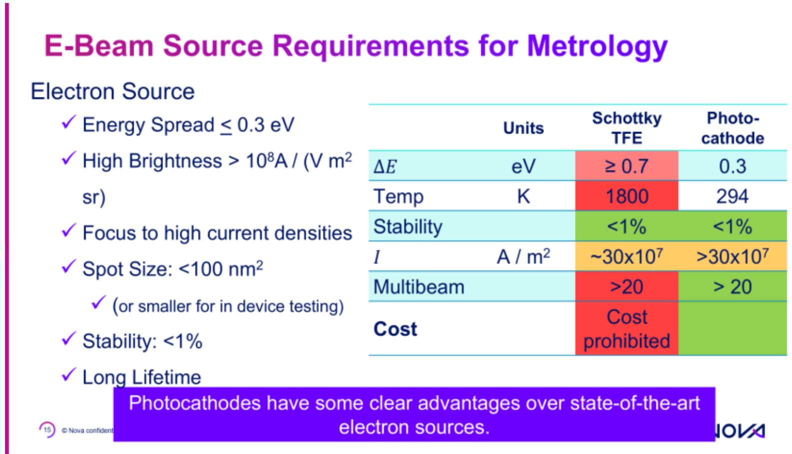




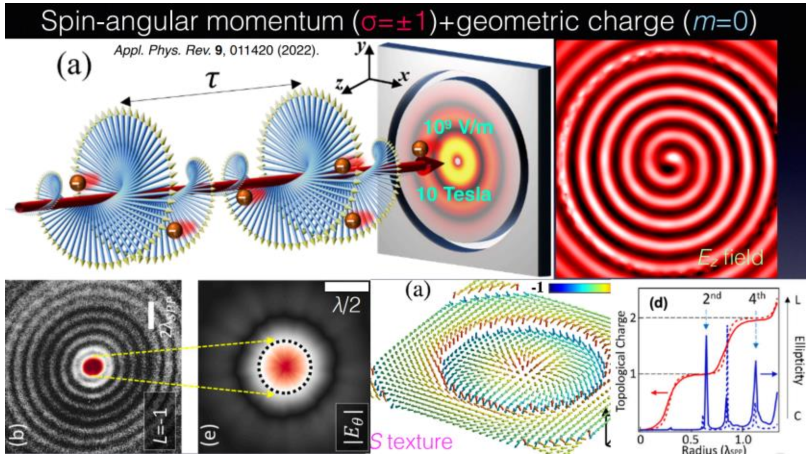


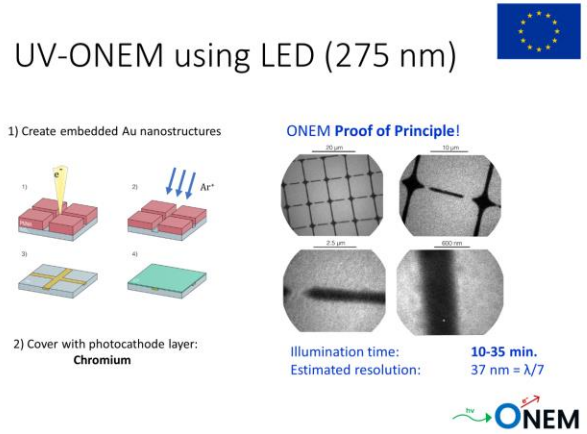






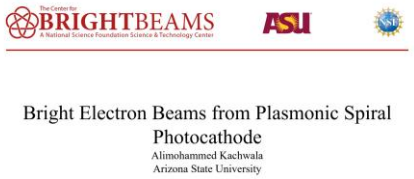
	Units	Schottky TFE	Photo-cathode
ΔE	eV	≥ 0.7	0.3
Temp	K	1800	294
Stability		<1%	<1%
I	A / m²	~30x10⁷	>30x10⁷
Multibeam		>20	> 20
Cost		Cost prohibited	



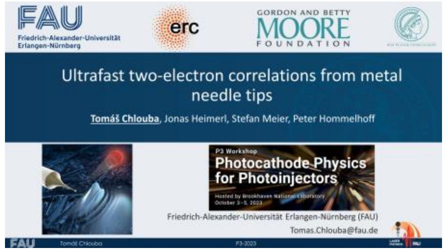


UED/UEM

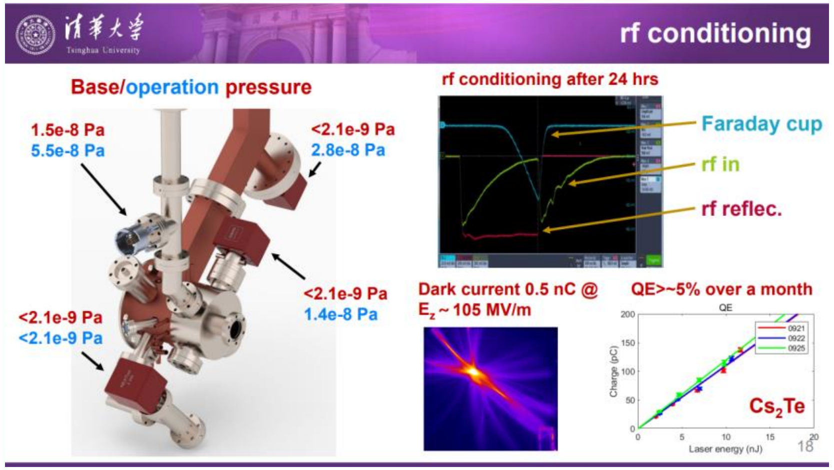
P3 Workshop
Photocathode Physics for Photoinjectors
清華大学
Tsinghua University
Photocathode sources studies
for UED/UEM at Tsinghua University
Renkai Li
Tsinghua University
2023/10/4



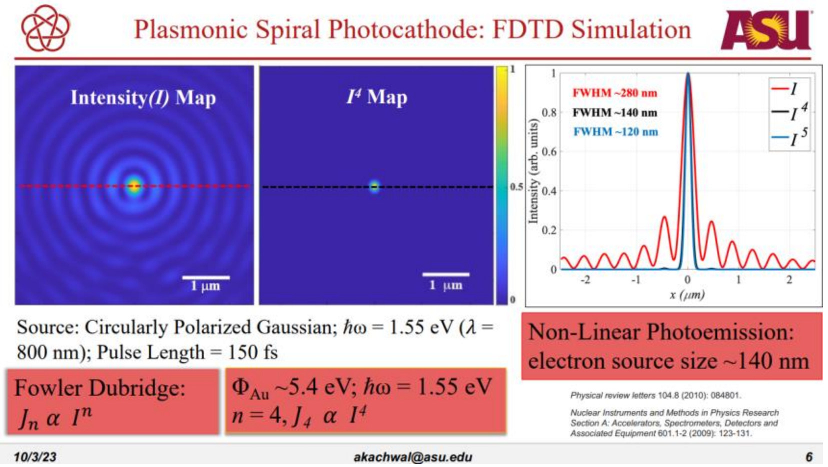
The Center for BRIGHTBEAMS
A National Science Foundation Science & Technology Center
ASU
Bright Electron Beams from Plasmonic Spiral Photocathode
Alimohammed Kachwala
Arizona State University



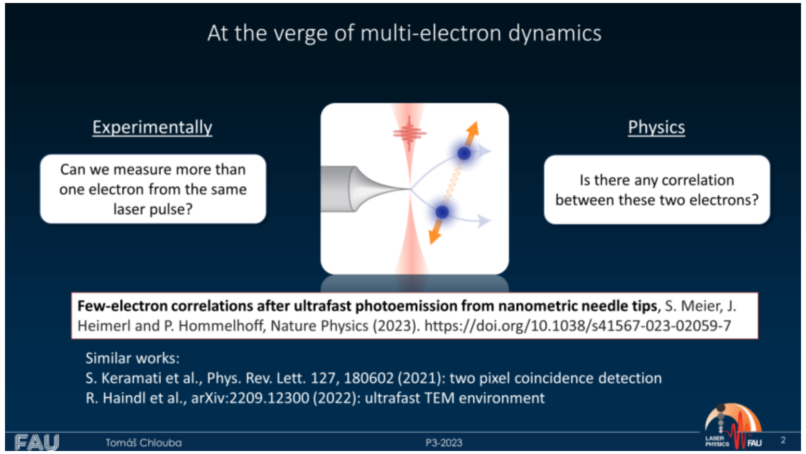
FAU
Friedrich-Alexander-Universität Erlangen-Nürnberg
erc
GORDON AND BETTY MOORE FOUNDATION
Ultrafast two-electron correlations from metal needle tips
Tomáš Chlouba, Jonas Heimerl, Stefan Meier, Peter Hommelhoff
P3 Workshop
Photocathode Physics for Photoinjectors
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)
Tomas.Chlouba@fau.de



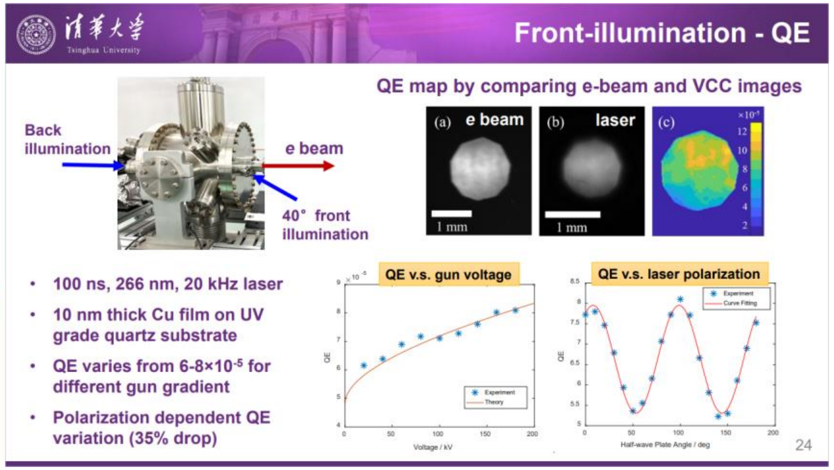
清華大学
Tsinghua University
rf conditioning
Base/operation pressure
1.5e-8 Pa
5.5e-8 Pa
<2.1e-9 Pa
2.8e-8 Pa
<2.1e-9 Pa
1.4e-8 Pa
<2.1e-9 Pa
<2.1e-9 Pa
rf conditioning after 24 hrs
Faraday cup
rf in
rf reflec.
Dark current 0.5 nC @ E_z ~ 105 MV/m
QE>~5% over a month
Cs_2Te
Laser energy (nJ)
Charge (pC)
18



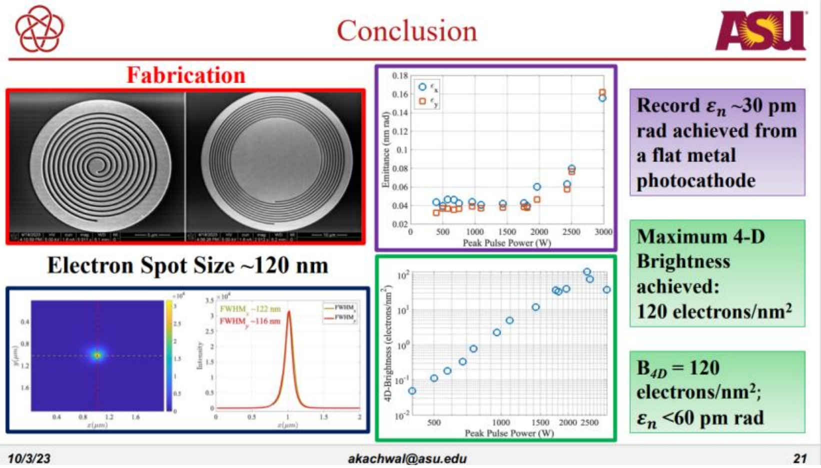
Plasmonic Spiral Photocathode: FDTD Simulation
ASU
Intensity(I) Map
I^4 Map
1 µm
FWHM ~280 nm
FWHM ~140 nm
FWHM ~120 nm
Intensity (arb. units)
x (µm)
Source: Circularly Polarized Gaussian; $\hbar\omega$ = 1.55 eV (λ = 800 nm); Pulse Length = 150 fs
Non-Linear Photoemission: electron source size ~140 nm
Fowler Dubridge: $J_n \; \alpha \; I^n$
Φ_{Au} ~5.4 eV; $\hbar\omega$ = 1.55 eV
$n = 4, J_4 \; \alpha \; I^4$
Physical review letters 104.8 (2010): 084801.
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 601.1-2 (2009): 123-131.
10/3/23
akachwal@asu.edu
6



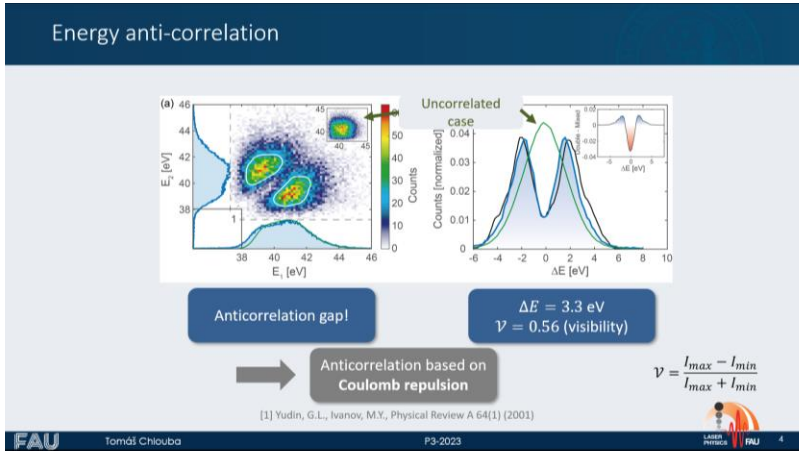
At the verge of multi-electron dynamics
Experimentally
Can we measure more than one electron from the same laser pulse?
Physics
Is there any correlation between these two electrons?
Few-electron correlations after ultrafast photoemission from nanometric needle tips, S. Meier, J. Heimerl and P. Hommelhoff, Nature Physics (2023). https://doi.org/10.1038/s41567-023-02059-7
Similar works:
S. Keramati et al., Phys. Rev. Lett. 127, 180602 (2021): two pixel coincidence detection
R. Haindl et al., arXiv:2209.12300 (2022): ultrafast TEM environment
FAU
Tomáš Chlouba
P3-2023
2



清華大学
Tsinghua University
Front-illumination - QE
QE map by comparing e-beam and VCC images
Back illumination
e beam
40° front illumination
(a) e beam
(b) laser
(c)
1 mm
• 100 ns, 266 nm, 20 kHz laser
• 10 nm thick Cu film on UV grade quartz substrate
• QE varies from 6-8×10⁻⁵ for different gun gradient
• Polarization dependent QE variation (35% drop)
QE v.s. gun voltage
Voltage / kV
QE v.s. laser polarization
Half-wave Plate Angle / deg
24

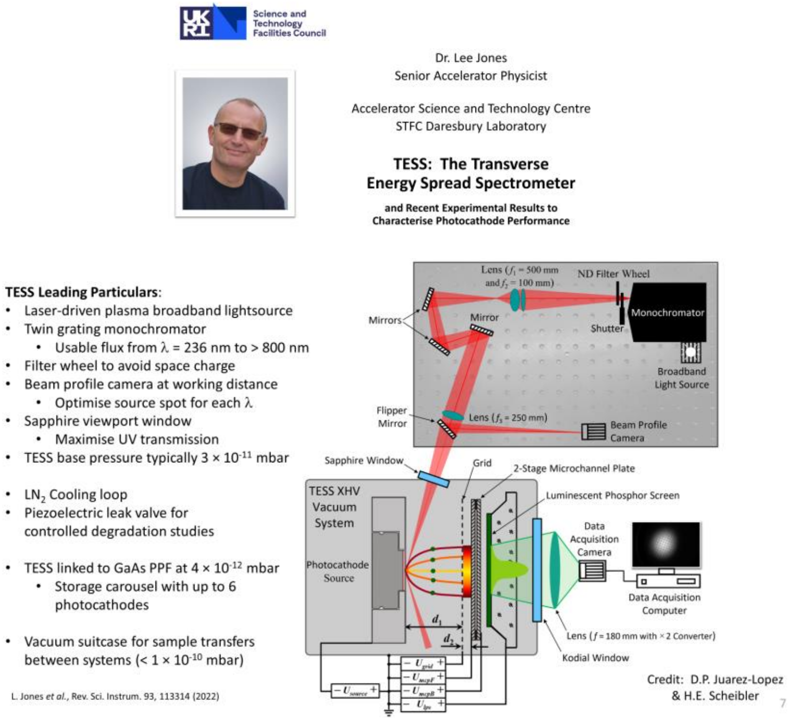


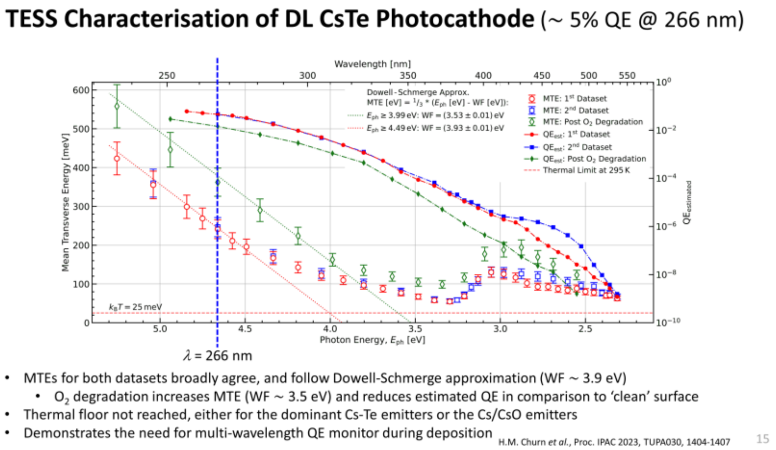
Conclusion
ASU
Fabrication
Electron Spot Size ~120 nm
Emittance (nm rad)
Peak Pulse Power (W)
4D-Brightness (electrons/nm²)
Record ε_n ~30 pm rad achieved from a flat metal photocathode
Maximum 4-D Brightness achieved: 120 electrons/nm²
B_{4D} = 120 electrons/nm²; ε_n <60 pm rad
10/3/23
akachwal@asu.edu
21



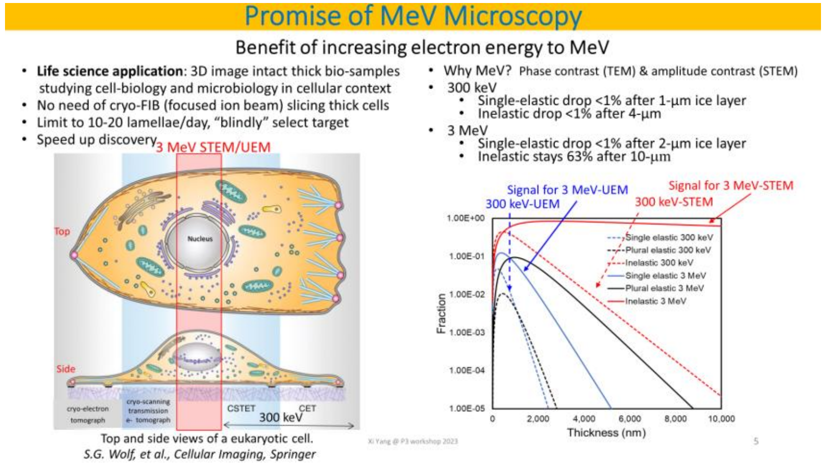
Energy anti-correlation
Uncorrelated case
E_2 [eV]
E_1 [eV]
Counts
Counts [normalized]
ΔE [eV]
Anticorrelation gap!
ΔE = 3.3 eV
$\mathcal{V}$ = 0.56 (visibility)
Anticorrelation based on Coulomb repulsion
$\mathcal{V} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
[1] Yudin, G.L., Ivanov, M.Y., Physical Review A 64(1) (2001)
FAU
Tomáš Chlouba
P3-2023
4

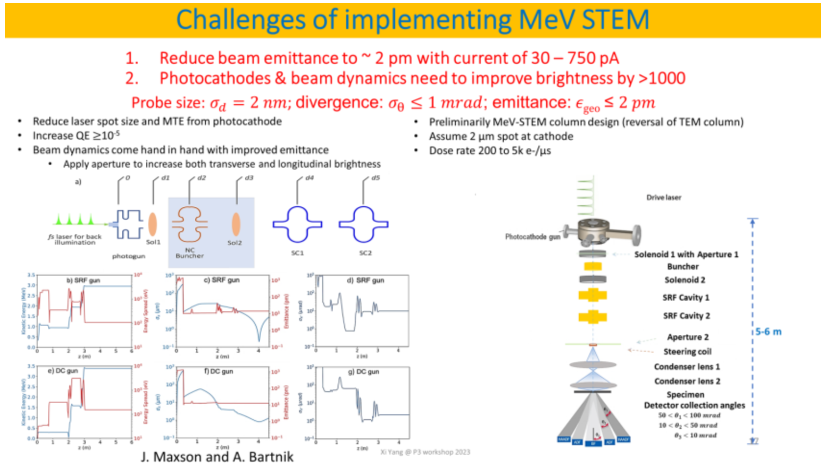
UED/UEM


Science and Technology Facilities Council
Dr. Lee Jones
Senior Accelerator Physicist
Accelerator Science and Technology Centre
STFC Daresbury Laboratory
TESS: The Transverse Energy Spread Spectrometer
and Recent Experimental Results to Characterise Photocathode Performance
TESS Leading Particulars:
• Laser-driven plasma broadband lightsource
• Twin grating monochromator
• Usable flux from λ = 236 nm to > 800 nm
• Filter wheel to avoid space charge
• Beam profile camera at working distance
• Optimise source spot for each λ
• Sapphire viewport window
• Maximise UV transmission
• TESS base pressure typically 3 × 10-11 mbar
• LN2 Cooling loop
• Piezoelectric leak valve for controlled degradation studies
• TESS linked to GaAs PPF at 4 × 10-12 mbar
• Storage carousel with up to 6 photocathodes
• Vacuum suitcase for sample transfers between systems (< 1 × 10-10 mbar)
L. Jones et al., Rev. Sci. Instrum. 93, 113314 (2022)
Mirrors
Mirror
ND Filter Wheel
Monochromator
Shutter
Broadband Light Source
Flipper Mirror
Beam Profile Camera
Sapphire Window
Grid
2-Stage Microchannel Plate
TESS XHV Vacuum System
Luminescent Phosphor Screen
Photocathode Source
Data Acquisition Camera
Data Acquisition Computer
Kodial Window
Credit: D.P. Juarez-Lopez & H.E. Scheibler
7

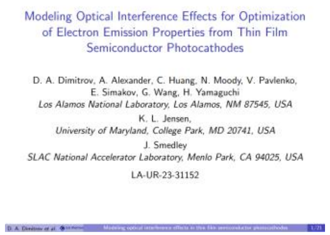

TESS Characterisation of DL CsTe Photocathode (~ 5% QE @ 266 nm)
Wavelength [nm]
Mean Transverse Energy [meV]
Photon Energy, Eph [eV]
λ = 266 nm
• MTEs for both datasets broadly agree, and follow Dowell-Schmerge approximation (WF ~ 3.9 eV)
• O2 degradation increases MTE (WF ~ 3.5 eV) and reduces estimated QE in comparison to 'clean' surface
• Thermal floor not reached, either for the dominant Cs-Te emitters or the Cs/CsO emitters
• Demonstrates the need for multi-wavelength QE monitor during deposition
H.M. Churn et al., Proc. IPAC 2023, TUPA030, 1404-1407
15


Brookhaven National Laboratory
ENERGY
Towards construction of a novel nm resolution MeV-STEM for imaging thick biological samples
Xi Yang
on behalf of BNL UEM team
in collaboration with Cornell university
10/04/2023

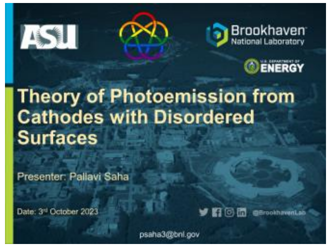

Promise of MeV Microscopy
Benefit of increasing electron energy to MeV
• Life science application: 3D image intact thick bio-samples studying cell-biology and microbiology in cellular context
• No need of cryo-FIB (focused ion beam) slicing thick cells
• Limit to 10-20 lamellae/day, "blindly" select target
• Speed up discovery
• Why MeV? Phase contrast (TEM) & amplitude contrast (STEM)
• 300 keV
• Single-elastic drop <1% after 1-μm ice layer
• Inelastic drop <1% after 4-μm
• 3 MeV
• Single-elastic drop <1% after 2-μm ice layer
• Inelastic stays 63% after 10-μm
3 MeV STEM/UEM
Signal for 3 MeV-UEM
300 keV-UEM
Signal for 3 MeV-STEM
300 keV-STEM
Fraction
Thickness (nm)
300 keV
Top and side views of a eukaryotic cell.
S.G. Wolf, et al., Cellular Imaging, Springer
5


Challenges of implementing MeV STEM
1. Reduce beam emittance to ~ 2 pm with current of 30 – 750 pA
2. Photocathodes & beam dynamics need to improve brightness by >1000
Probe size: σd = 2 nm; divergence: σθ ≤ 1 mrad; emittance: εgeo ≤ 2 pm
• Reduce laser spot size and MTE from photocathode
• Increase QE ≥10-5
• Beam dynamics come hand in hand with improved emittance
• Apply aperture to increase both transverse and longitudinal brightness
• Preliminarily MeV-STEM column design (reversal of TEM column)
• Assume 2 μm spot at cathode
• Dose rate 200 to 5k e-/μs
Drive laser
Photocathode gun
Solenoid 1 with Aperture 1
Buncher
Solenoid 2
SRF Cavity 1
SRF Cavity 2
Aperture 2
Steering coil
Condenser lens 1
Condenser lens 2
Specimen
Detector collection angles
5-6 m
J. Maxson and A. Bartnik

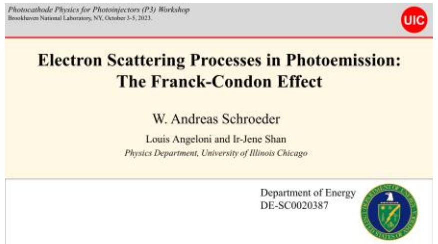
Theory



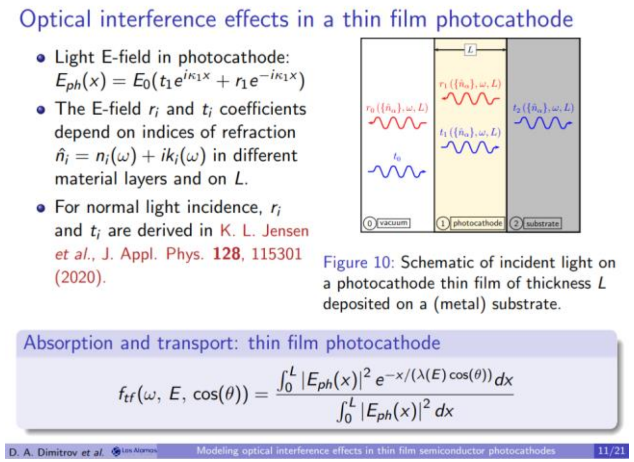
Modeling Optical Interference Effects for Optimization of Electron Emission Properties from Thin Film Semiconductor Photocathodes
D. A. Dimitrov, A. Alexander, C. Huang, N. Moody, V. Pavlenko, E. Simakov, G. Wang, H. Yamaguchi
Los Alamos National Laboratory, Los Alamos, NM 87545, USA
K. L. Jensen,
University of Maryland, College Park, MD 20741, USA
J. Smedley
SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA
LA-UR-23-31152



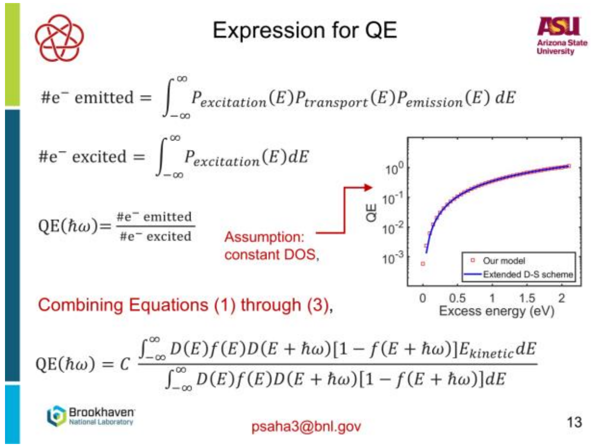
ASU
Brookhaven National Laboratory
ENERGY
Theory of Photoemission from Cathodes with Disordered Surfaces
Presenter: Pallavi Saha
Date: 3rd October 2023
psaha3@bnl.gov



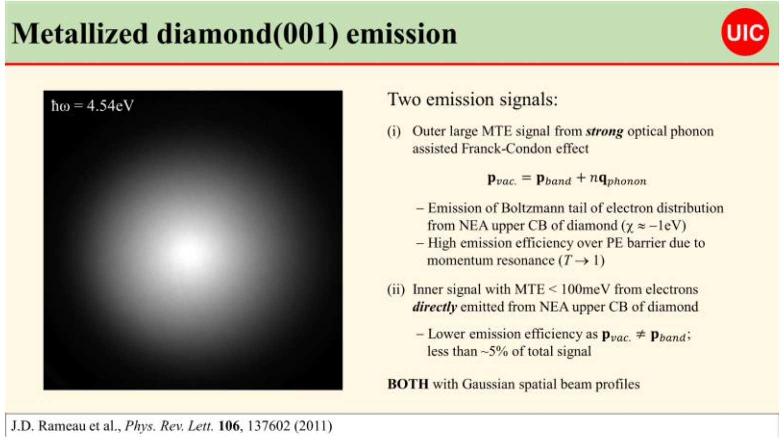
Photocathode Physics for Photoinjectors (P3) Workshop
Brookhaven National Laboratory, NY, October 3-5, 2023.
UIC
Electron Scattering Processes in Photoemission: The Franck-Condon Effect
W. Andreas Schroeder
Louis Angeloni and Ir-Jene Shan
Physics Department, University of Illinois Chicago
Department of Energy
DE-SC0020387



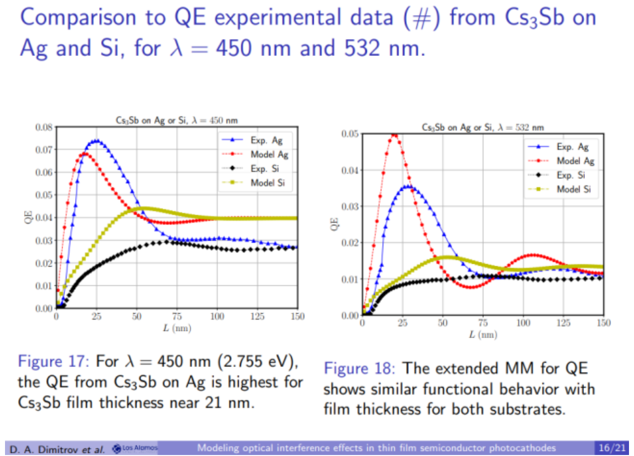
Optical interference effects in a thin film photocathode
Light E-field in photocathode: $E_{ph}(x) = E_0(t_1 e^{i\kappa_1 x} + r_1 e^{-i\kappa_1 x})$
The E-field r_i and t_i coefficients depend on indices of refraction $\hat{n}_i = n_i(\omega) + ik_i(\omega)$ in different material layers and on L.
For normal light incidence, r_i and t_i are derived in K. L. Jensen et al., J. Appl. Phys. 128, 115301 (2020).
vacuum
photocathode
substrate
Figure 10: Schematic of incident light on a photocathode thin film of thickness L deposited on a (metal) substrate.
Absorption and transport: thin film photocathode
$f_{tf}(\omega, E, \cos(\theta)) = \frac{\int_0^L |E_{ph}(x)|^2 e^{-x/(\lambda(E)\cos(\theta))} dx}{\int_0^L |E_{ph}(x)|^2 dx}$
D. A. Dimitrov et al.
Modeling optical interference effects in thin film semiconductor photocathodes
11/21



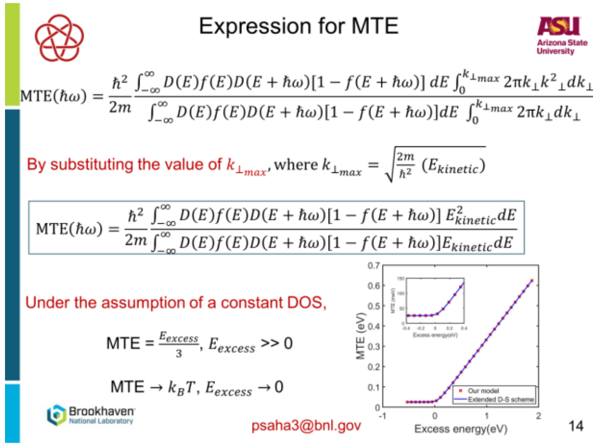
Expression for QE
Arizona State University
$\#e^- \text{ emitted} = \int_{-\infty}^{\infty} P_{excitation}(E) P_{transport}(E) P_{emission}(E)\, dE$
$\#e^- \text{ excited} = \int_{-\infty}^{\infty} P_{excitation}(E)\, dE$
$QE(\hbar\omega) = \frac{\#e^- \text{ emitted}}{\#e^- \text{ excited}}$
Assumption: constant DOS,
Our model
Extended D-S scheme
Excess energy (eV)
QE
Combining Equations (1) through (3),
$QE(\hbar\omega) = C \frac{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)] E_{kinetic}\, dE}{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)]\, dE}$
Brookhaven National Laboratory
psaha3@bnl.gov
13



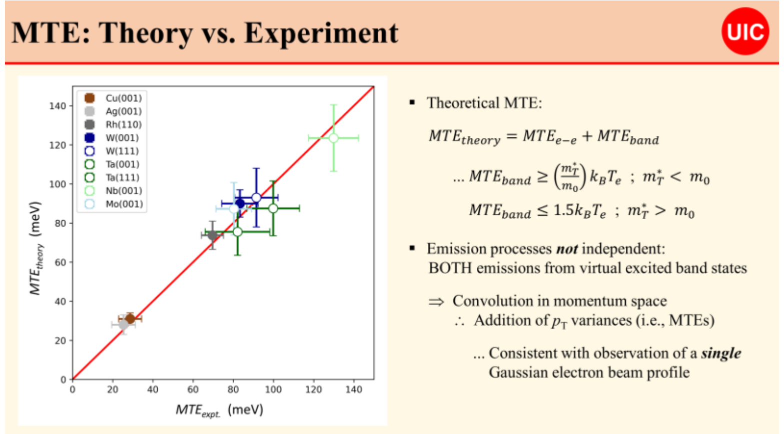
Metallized diamond(001) emission
UIC
ħω = 4.54eV
Two emission signals:
(i) Outer large MTE signal from strong optical phonon assisted Franck-Condon effect
$\mathbf{p}_{vac.} = \mathbf{p}_{band} + n\mathbf{q}_{phonon}$
– Emission of Boltzmann tail of electron distribution from NEA upper CB of diamond ($\chi \approx -1$eV)
– High emission efficiency over PE barrier due to momentum resonance ($T \to 1$)
(ii) Inner signal with MTE < 100meV from electrons directly emitted from NEA upper CB of diamond
– Lower emission efficiency as $\mathbf{p}_{vac.} \neq \mathbf{p}_{band}$; less than ~5% of total signal
BOTH with Gaussian spatial beam profiles
J.D. Rameau et al., Phys. Rev. Lett. 106, 137602 (2011)



Comparison to QE experimental data (#) from Cs_3Sb on Ag and Si, for λ = 450 nm and 532 nm.
Cs3Sb on Ag or Si, λ = 450 nm
Cs3Sb on Ag or Si, λ = 532 nm
Exp. Ag
Model Ag
Exp. Si
Model Si
QE
L (nm)
Figure 17: For λ = 450 nm (2.755 eV), the QE from Cs_3Sb on Ag is highest for Cs_3Sb film thickness near 21 nm.
Figure 18: The extended MM for QE shows similar functional behavior with film thickness for both substrates.
D. A. Dimitrov et al.
Modeling optical interference effects in thin film semiconductor photocathodes
16/21

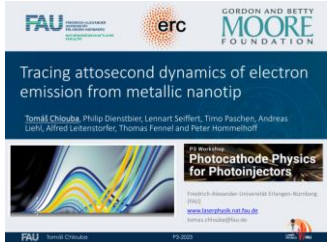


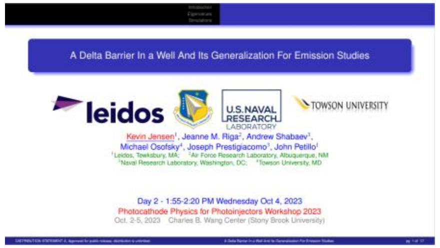
Expression for MTE
Arizona State University
$MTE(\hbar\omega) = \frac{\hbar^2}{2m} \frac{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)]\, dE \int_0^{k_{\perp max}} 2\pi k_\perp k_\perp^2 dk_\perp}{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)]\, dE \int_0^{k_{\perp max}} 2\pi k_\perp dk_\perp}$
By substituting the value of $k_{\perp max}$, where $k_{\perp max} = \sqrt{\frac{2m}{\hbar^2}(E_{kinetic})}$
$MTE(\hbar\omega) = \frac{\hbar^2}{2m} \frac{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)] E_{kinetic}^2\, dE}{\int_{-\infty}^{\infty} D(E) f(E) D(E+\hbar\omega)[1-f(E+\hbar\omega)] E_{kinetic}\, dE}$
Under the assumption of a constant DOS,
$MTE = \frac{E_{excess}}{3}$, $E_{excess} >> 0$
$MTE \to k_B T$, $E_{excess} \to 0$
MTE (eV)
Excess energy(eV)
Our model
Extended D-S scheme
Brookhaven National Laboratory
psaha3@bnl.gov
14



MTE: Theory vs. Experiment
UIC
Cu(001)
Ag(001)
Rh(110)
W(001)
W(111)
Ta(001)
Ta(111)
Nb(001)
Mo(001)
MTE_{theory} (meV)
$MTE_{expt.}$ (meV)
Theoretical MTE:
$MTE_{theory} = MTE_{e-e} + MTE_{band}$
... $MTE_{band} \geq \left(\frac{m_T^*}{m_0}\right) k_B T_e$; $m_T^* < m_0$
$MTE_{band} \leq 1.5 k_B T_e$; $m_T^* > m_0$
Emission processes not independent: BOTH emissions from virtual excited band states
⇒ Convolution in momentum space
∴ Addition of p_T variances (i.e., MTEs)
... Consistent with observation of a single Gaussian electron beam profile

Theory


Tracing attosecond dynamics of electron emission from metallic nanotip
Tomáš Chlouba, Philip Dienstbier, Lennart Seiffert, Timo Paschen, Andreas Liehl, Alfred Leitenstorfer, Thomas Fennel and Peter Hommelhoff
Photocathode Physics for Photoinjectors
Tomáš Chlouba
P3-2023


A Delta Barrier In a Well And Its Generalization For Emission Studies
leidos
U.S. NAVAL RESEARCH LABORATORY
TOWSON UNIVERSITY
Kevin Jensen, Jeanne M. Riga, Andrew Shabaev, Michael Osofsky, Joseph Prestigiacomo, John Petillo
Day 2 - 1:55-2:20 PM Wednesday Oct 4, 2023
Photocathode Physics for Photoinjectors Workshop 2023
Oct. 2-5, 2023 Charles B. Wang Center (Stony Brook University)


P3 2023
2023 Photocathode Physics for Photoinjectors Workshop
Brookhaven National Laboratory
3-5 October 2023
Theory Session
Beam Transport Parameter Sensitivities Using Adjoint Methods for 2D Axisymmetric Systems in Static Fields with MICHELLE
John Petillo
This work was supported by Navy contract N68335-22-C-0004 and Leidos IR&D
Distribution A: Approved for Release. Distribution is unlimited.
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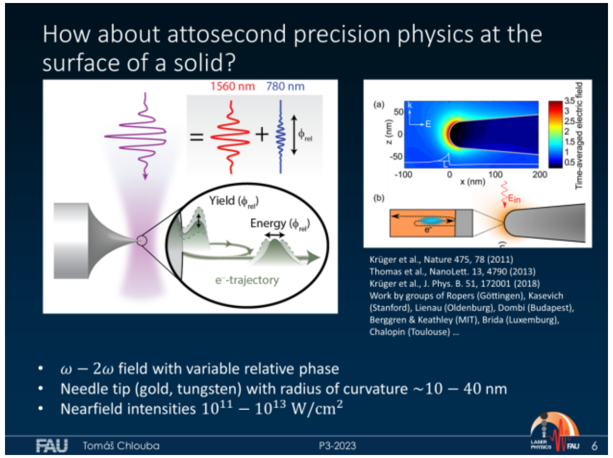
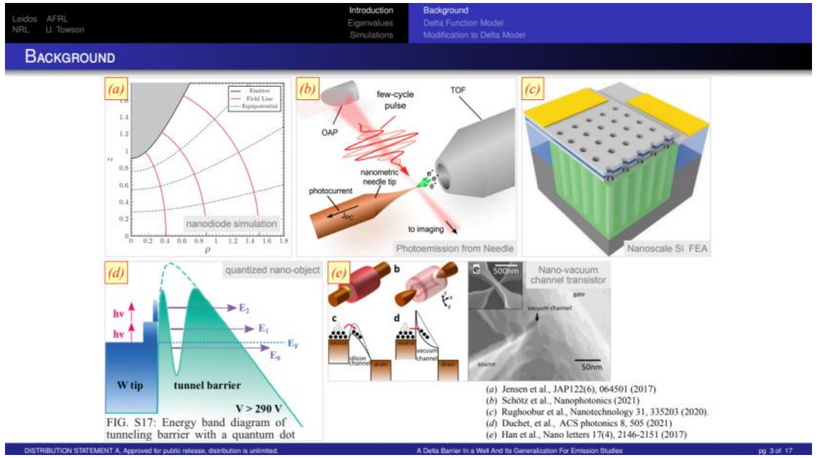
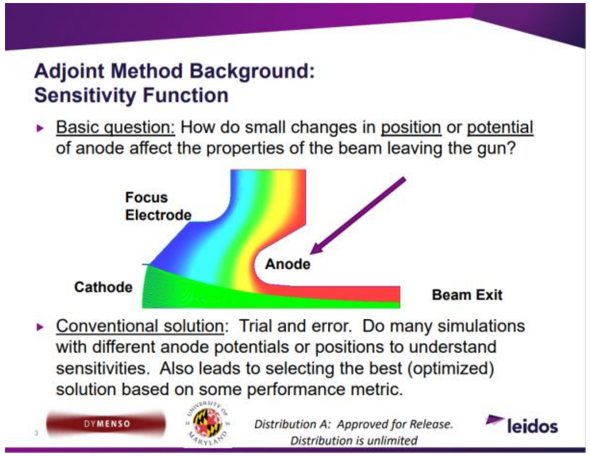

How about attosecond precision physics at the surface of a solid?
1560 nm 780 nm
Yield
Energy
e⁻-trajectory
Krüger et al., Nature 475, 78 (2011)
Thomas et al., NanoLett. 13, 4790 (2013)
Krüger et al., J. Phys. B. 51, 172001 (2018)
Work by groups of Ropers (Göttingen), Kasevich (Stanford), Lienau (Oldenburg), Dombi (Budapest), Berggren & Keathley (MIT), Brida (Luxemburg), Chalopin (Toulouse) ...
• $\omega - 2\omega$ field with variable relative phase
• Needle tip (gold, tungsten) with radius of curvature ~10 – 40 nm
• Nearfield intensities $10^{11} - 10^{13}$ W/cm^2
FAU Tomáš Chlouba P3-2023 6


Background
nanodiode simulation
Photoemission from Needle
Nanoscale Si FEA
quantized nano-object
Nano-vacuum channel transistor
W tip
tunnel barrier
V > 290 V
FIG. S17: Energy band diagram of tunneling barrier with a quantum dot
(a) Jensen et al., JAP122(6), 064501 (2017)
(b) Schötz et al., Nanophotonics (2021)
(c) Rughoobur et al., Nanotechnology 31, 335203 (2020).
(d) Duchet, et al., ACS photonics 8, 505 (2021)
(e) Han et al., Nano letters 17(4), 2146-2151 (2017)
DISTRIBUTION STATEMENT A. Approved for public release, distribution is unlimited.
A Delta Barrier In a Well And Its Generalization For Emission Studies
pg 3 of 17


Adjoint Method Background: Sensitivity Function
Basic question: How do small changes in position or potential of anode affect the properties of the beam leaving the gun?
Focus Electrode
Anode
Cathode
Beam Exit
Conventional solution: Trial and error. Do many simulations with different anode potentials or positions to understand sensitivities. Also leads to selecting the best (optimized) solution based on some performance metric.
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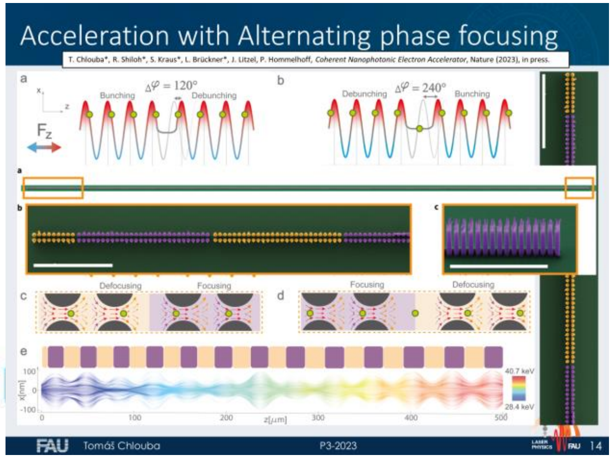
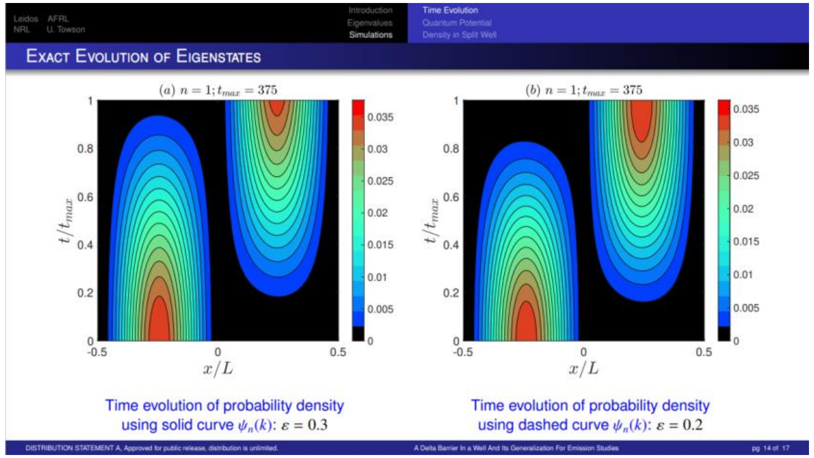
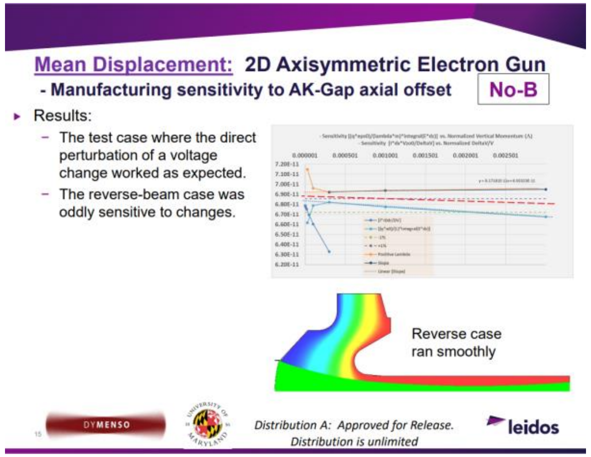
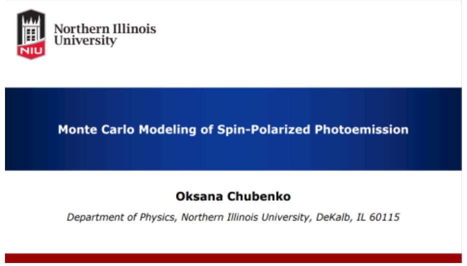
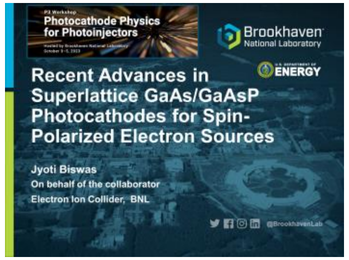

Acceleration with Alternating phase focusing
T. Chlouba*, R. Shiloh*, S. Kraus*, L. Brückner*, J. Litzel, P. Hommelhoff, Coherent Nanophotonic Electron Accelerator, Nature (2023), in press.
Bunching
Debunching
Defocusing
Focusing
40.7 keV
28.4 keV
FAU Tomáš Chlouba P3-2023 14

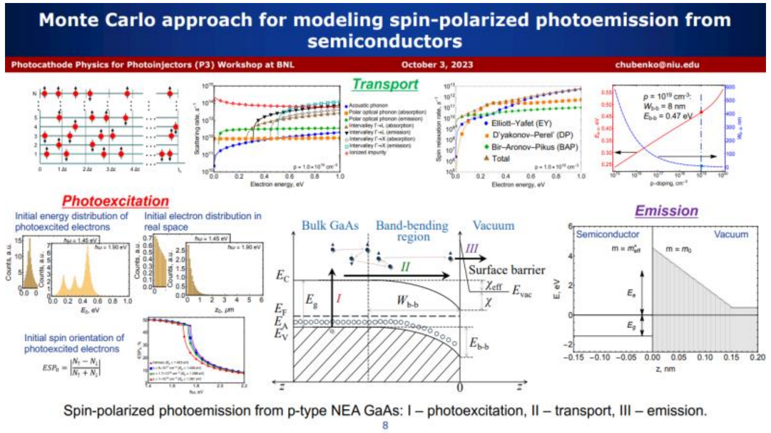

Exact Evolution of Eigenstates
$(a)\ n = 1; t_{max} = 375$
$(b)\ n = 1; t_{max} = 375$
t/t_{max}
x/L
Time evolution of probability density using solid curve $\psi_n(k)$: $\varepsilon = 0.3$
Time evolution of probability density using dashed curve $\psi_n(k)$: $\varepsilon = 0.2$
DISTRIBUTION STATEMENT A. Approved for public release, distribution is unlimited.
A Delta Barrier In a Well And Its Generalization For Emission Studies
pg 14 of 17

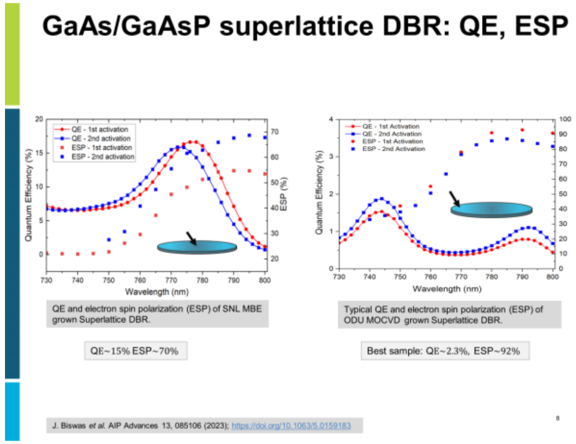

Mean Displacement: 2D Axisymmetric Electron Gun
- Manufacturing sensitivity to AK-Gap axial offset
No-B
Results:
– The test case where the direct perturbation of a voltage change worked as expected.
– The reverse-beam case was oddly sensitive to changes.
Reverse case ran smoothly
Distribution A: Approved for Release. Distribution is unlimited
leidos

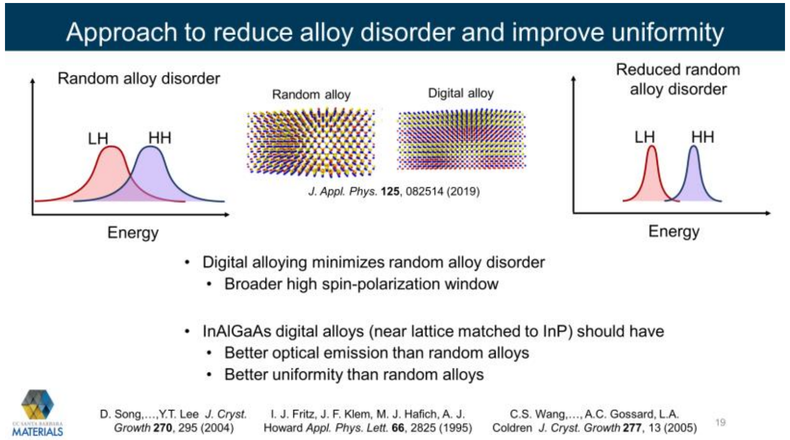
Spin polarized

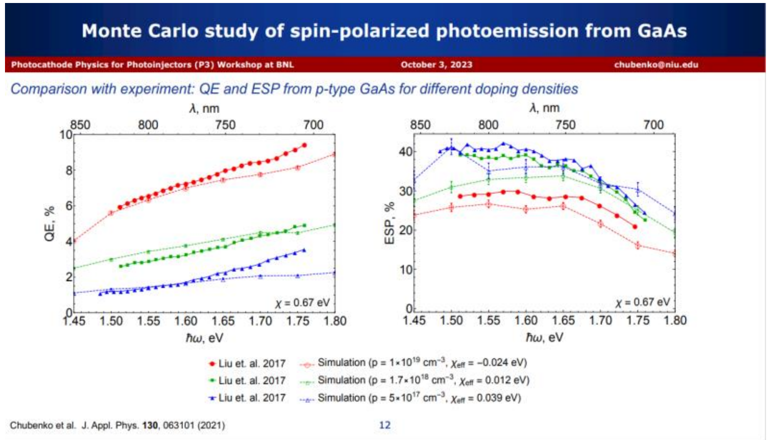


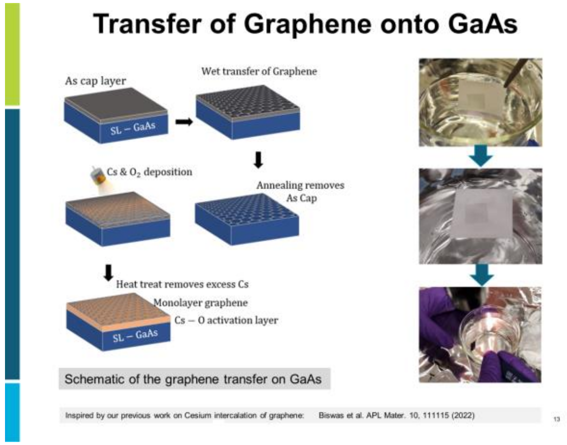


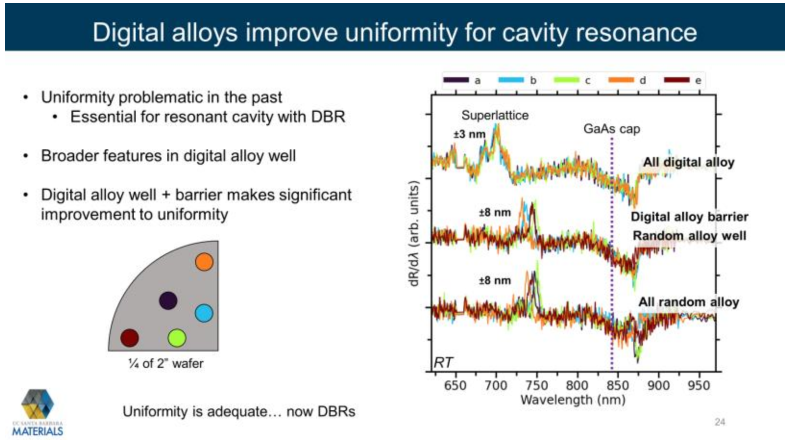




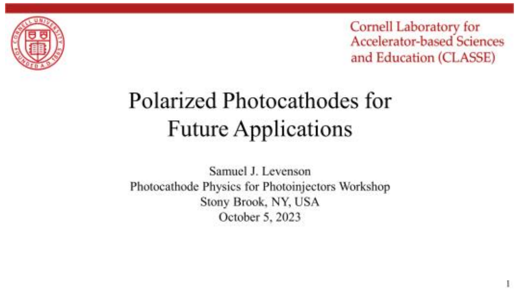


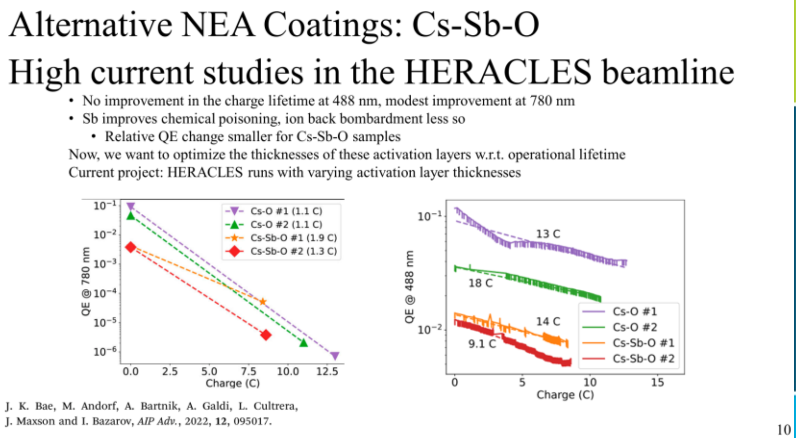


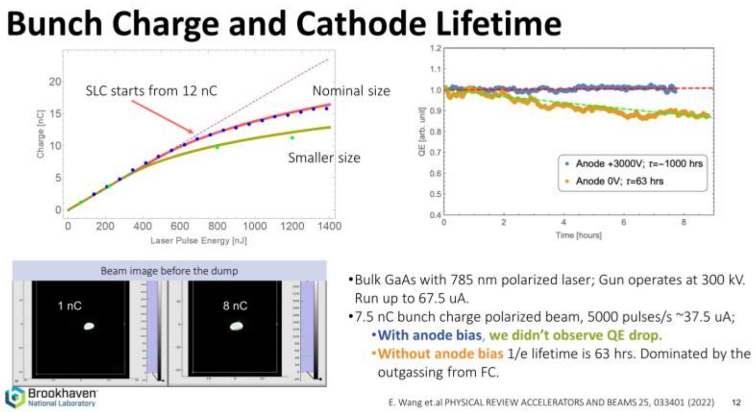


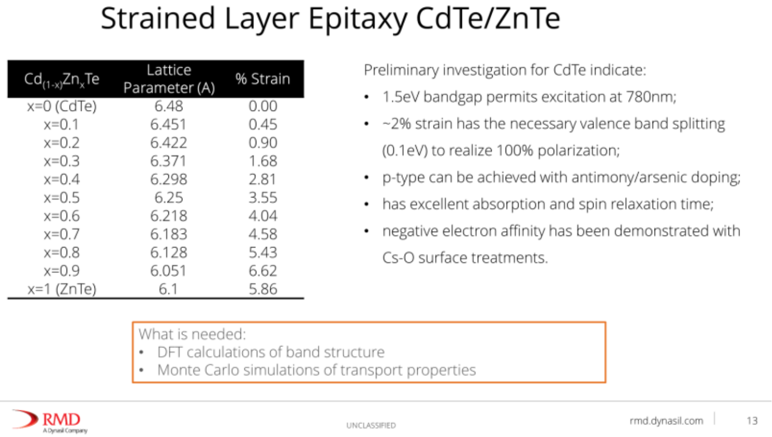


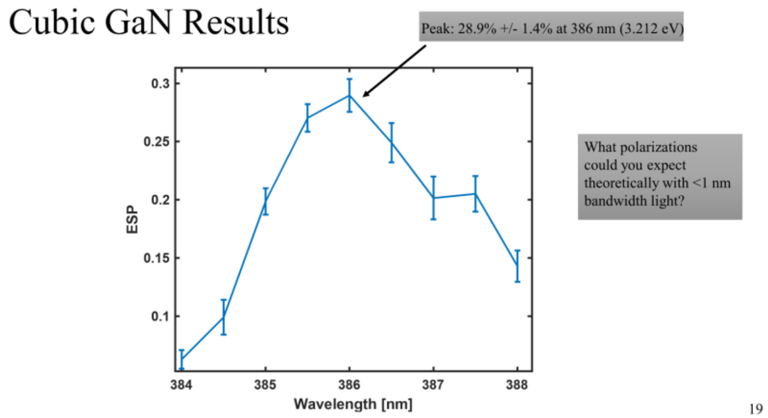
Spin polarized

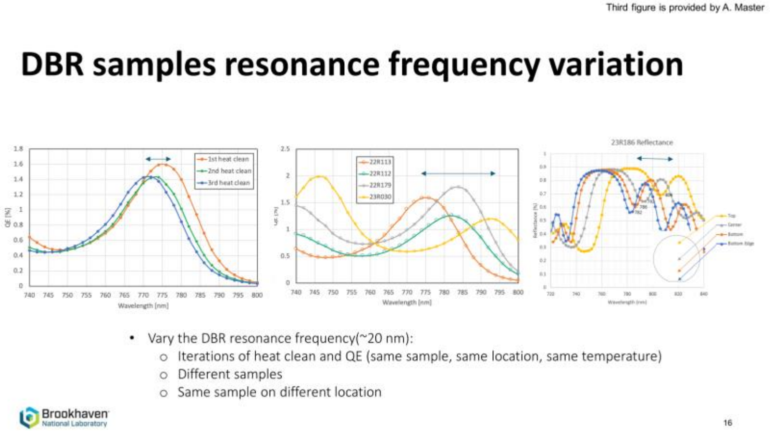


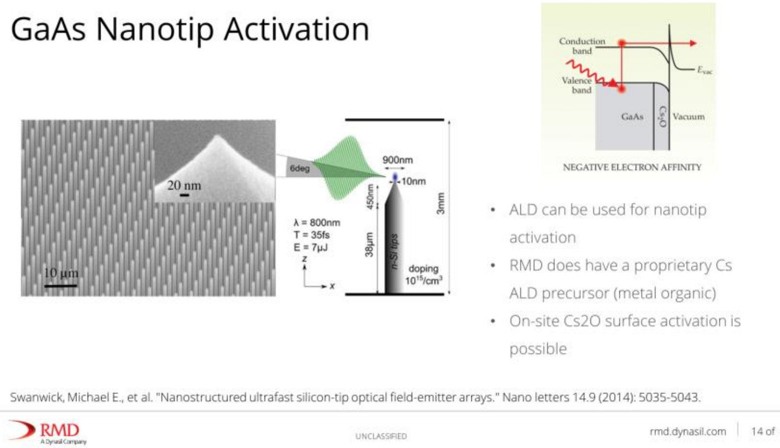












P3 2025: Welcome to the Desert

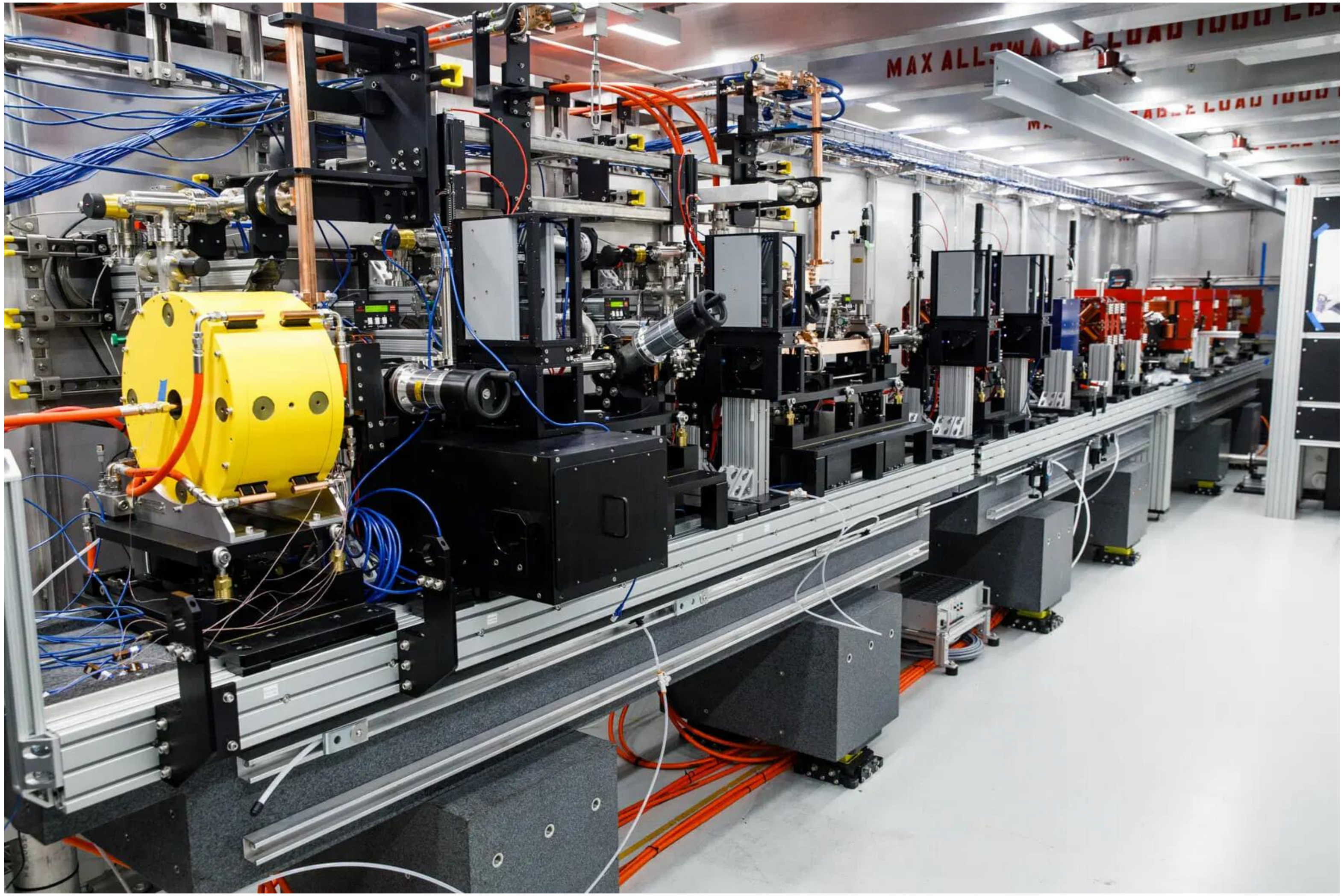
ARIZONA STATE UNIVERSITY

Beus CXFEL Lab

10 MeV linac based Incoherent Compton X-ray source – first x-rays

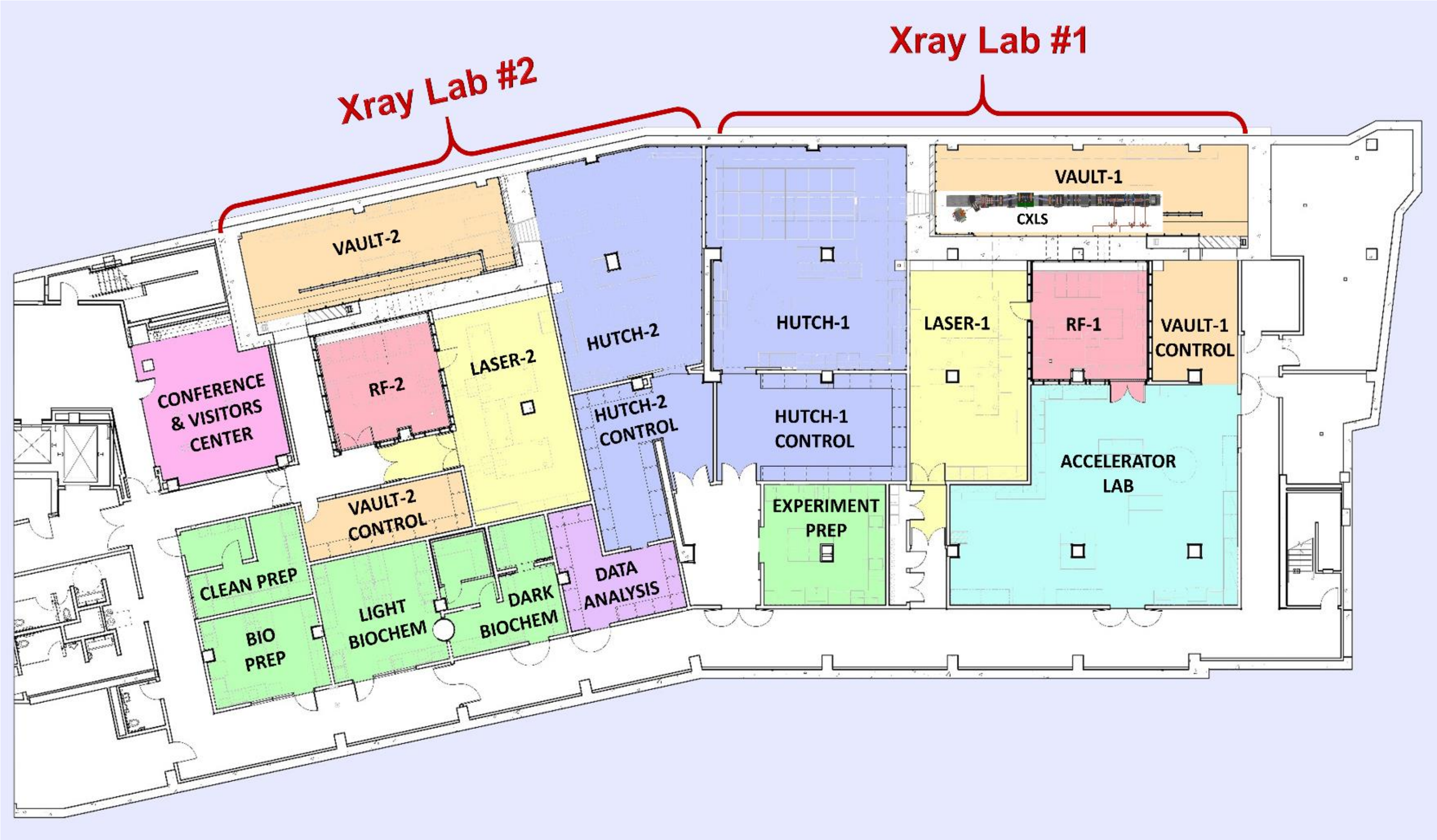
$90M NSF X-ray facility

Coherent X-ray Compton source research



Brookhaven National Laboratory

Beus CXFEL Lab



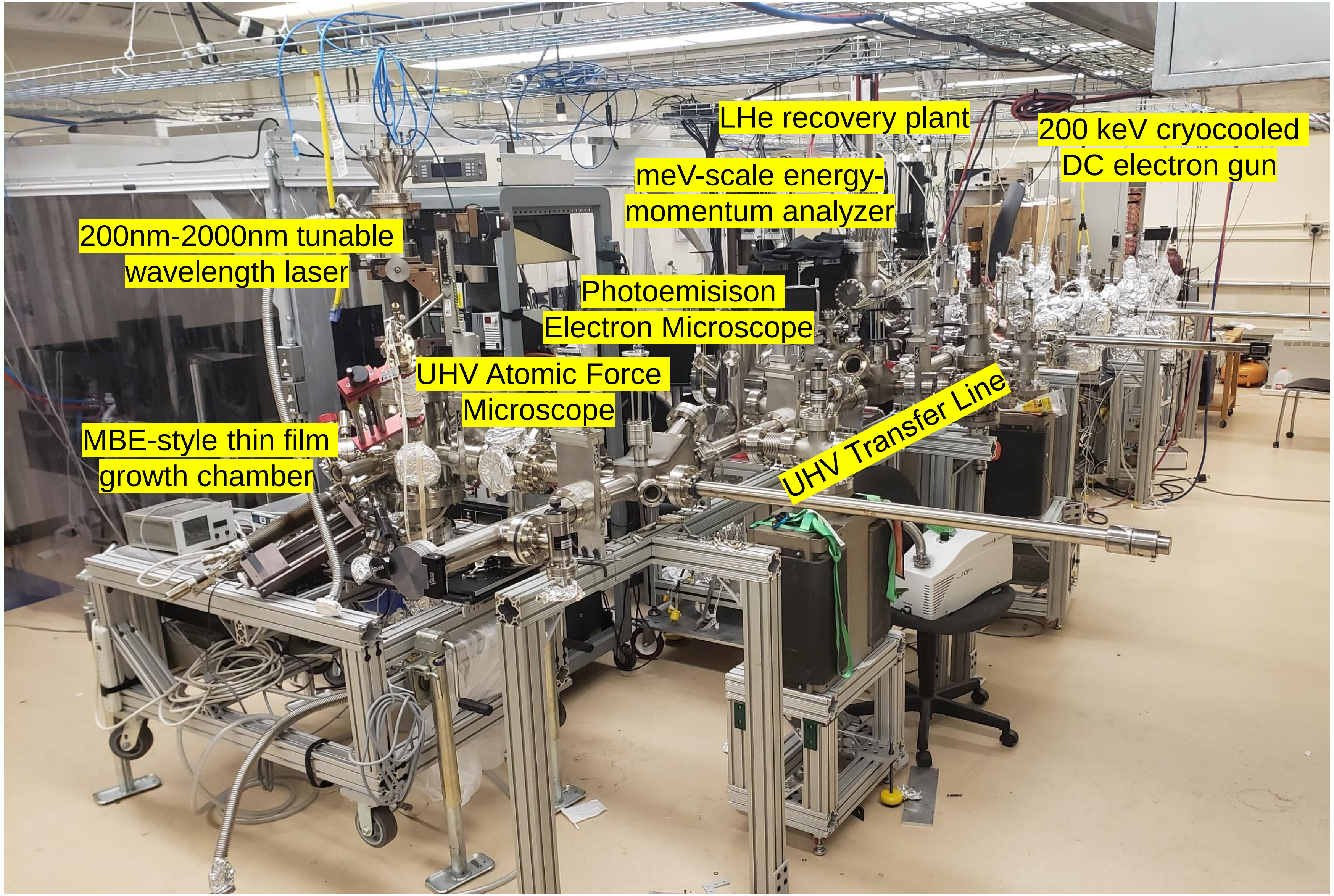
Unique ultra-stable photoinjector facility

2 vaults:

- Vibration free
- EM free
- Radiation shielded

Large Dedicated X-ray 'hutches' + prep labs

Photoemission and Bright Beams Lab



UHV thin film growth

Atomic scale surface characterization

Fundamental photoemission physics

Electron Beam Physics

Ultrafast Electron Diffraction (soon)

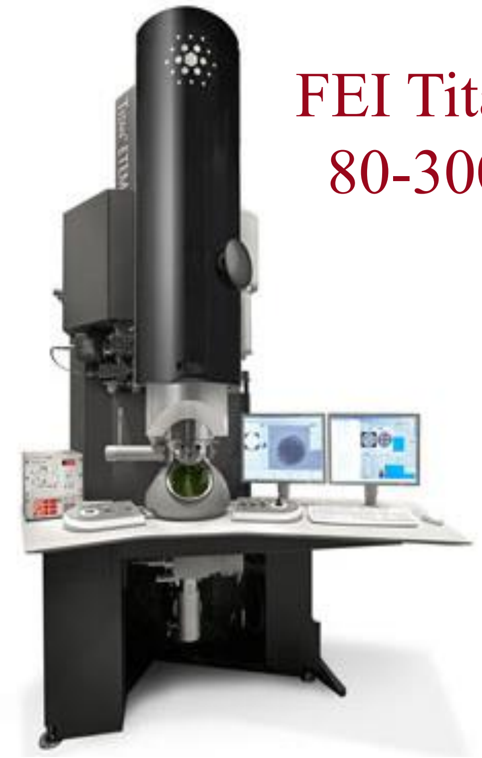
John M. Cowley Center for High Resolution Electron Microscopy

Nion UltraSTEM100

Sub-Å spatial resolution
Sub-10 meV energy spread

JEOL ARM200F

FEI Titan 80-300



- Vibrational Spectroscopy in EM
- Aloof EM
- Lorentz EM …

Nanofab and Eyring Materials Center

Brookhaven National Laboratory

Large University Campus

- Strong expertise in nanoscience and ultrafast physics and upcoming accelerator physics
- >60,000 students

Brookhaven National Laboratory

P3 2025: See you next year

But will it still be P3…?

ASU ARIZONA STATE UNIVERSITY

Thank you!!!

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