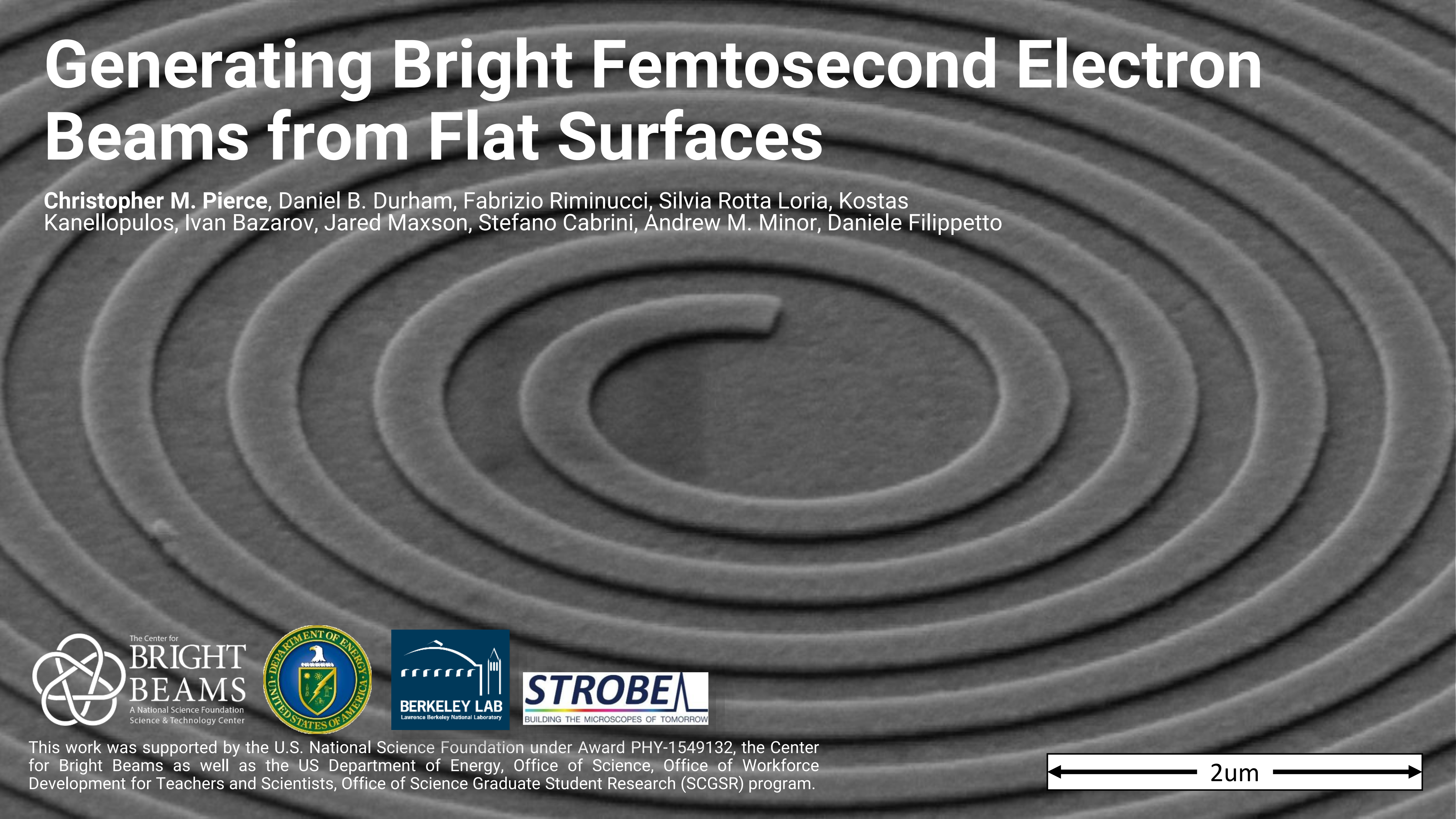
Generating Bright Femtosecond Electron Beams from Flat Surfaces

Christopher M. Pierce, Daniel B. Durham, Fabrizio Riminucci, Silvia Rotta Loria, Kostas Kanellopulos, Ivan Bazarov, Jared Maxson, Stefano Cabrini, Andrew M. Minor, Daniele Filippetto



The Center for BRIGHT BEAMS A National Science Foundation Science & Technology Center

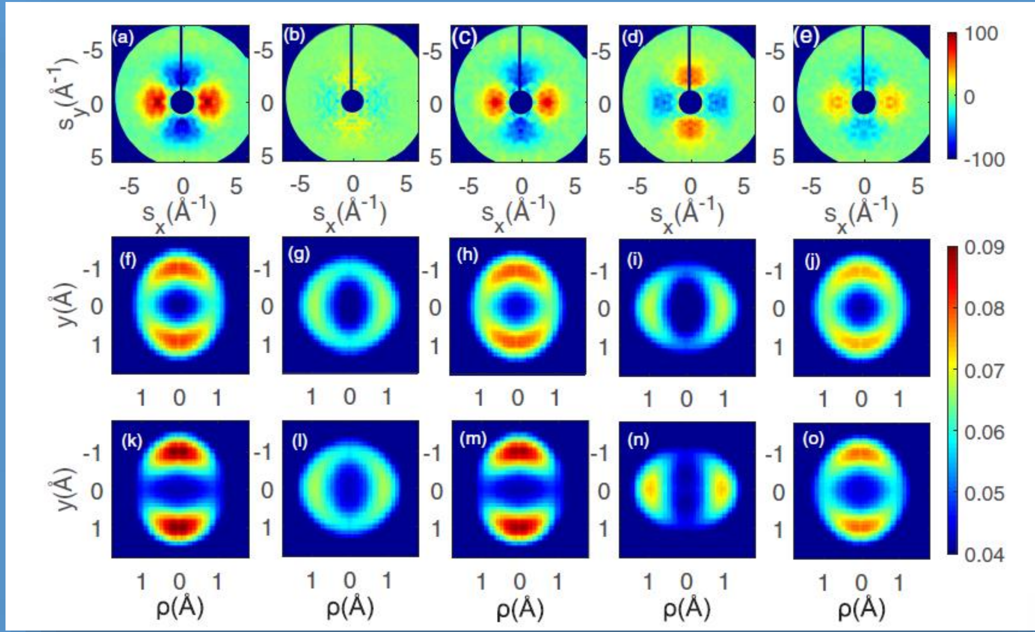
BERKELEY LAB Lawrence Berkeley National Laboratory

STROBE BUILDING THE MICROSCOPES OF TOMORROW

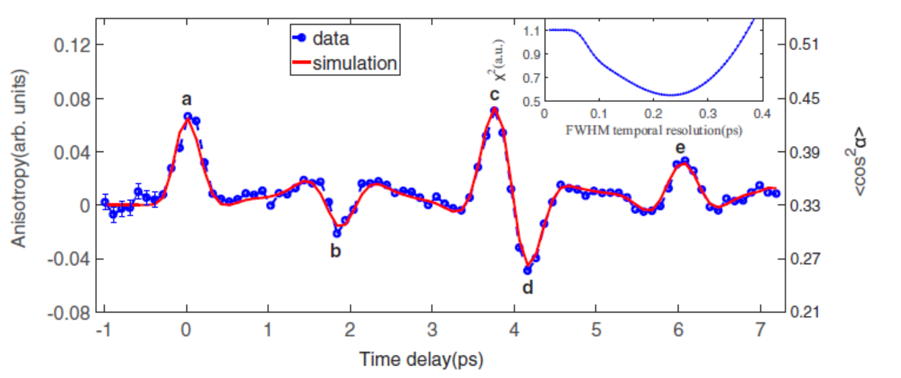
This work was supported by the U.S. National Science Foundation under Award PHY-1549132, the Center for Bright Beams as well as the US Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program.

The Need for Bright Femtosecond Electron Beams

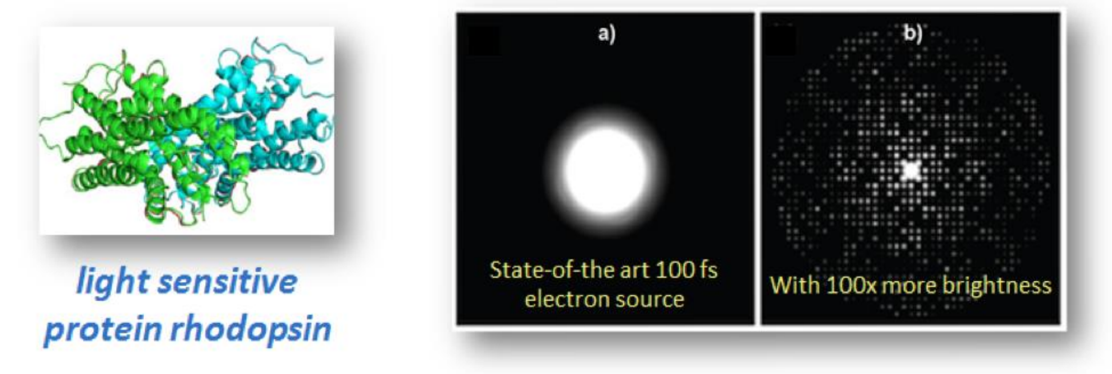
UED – Structural Time Resolved Atomic Scale Probes



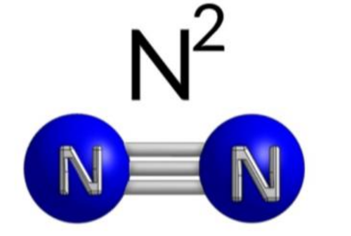
Xiong, Y., Wilkin, K. J., & Centurion, M. (2020) *Physical Review Research*, *2*(4), 043064.

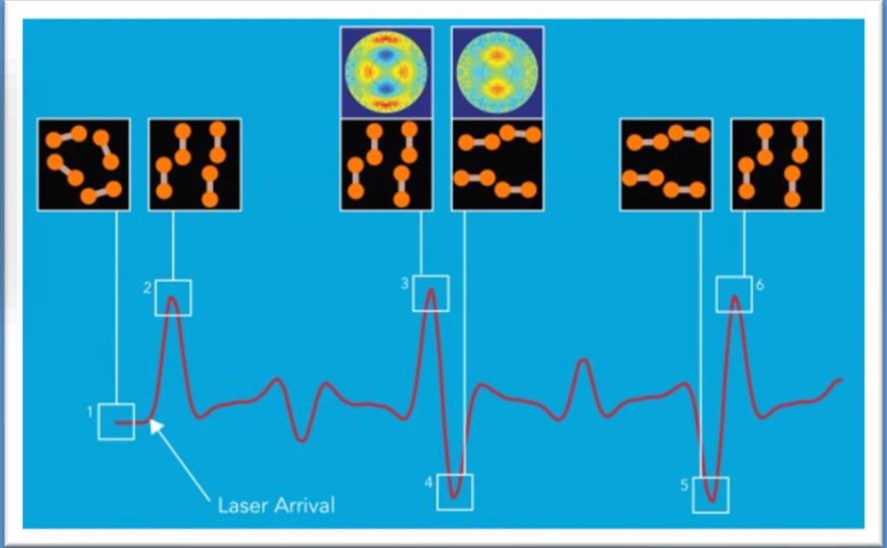


Source Brightness is Barrier to UED on complex systems



Center for Bright Beams Collaboration





The Need for Bright Femtosecond Electron Beams

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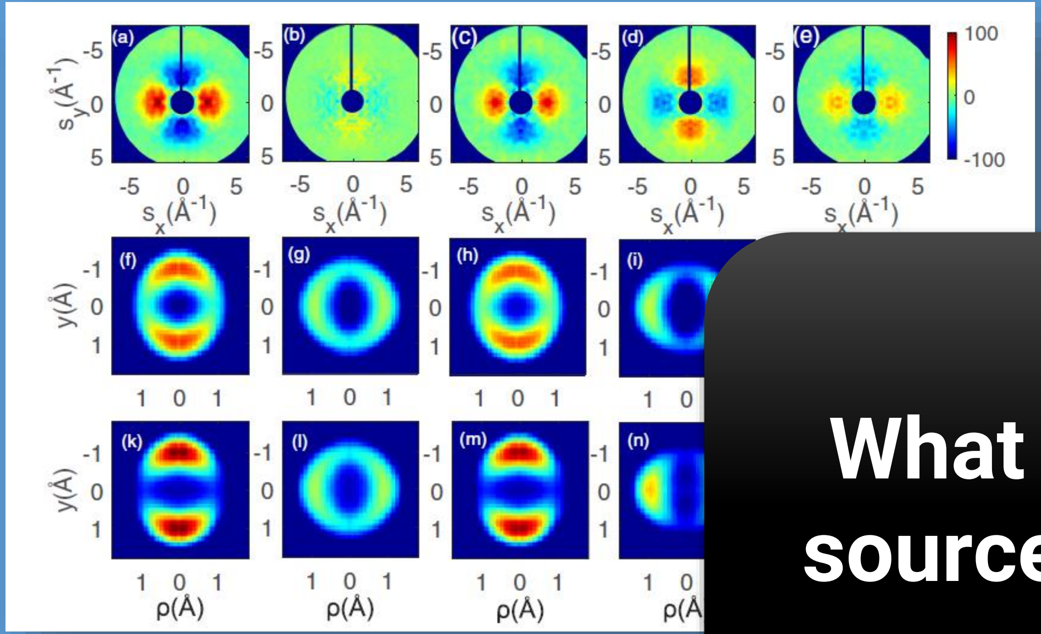
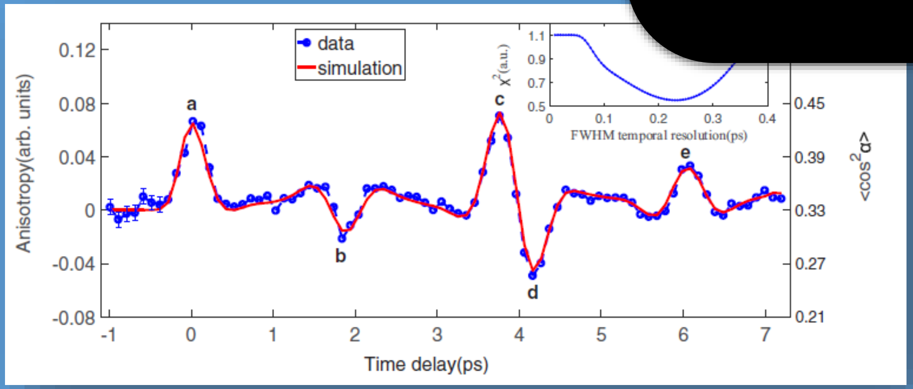


Xiong, Y., Wilkin, K. J., & Centurion, M. (2020) *Physical Review Res*



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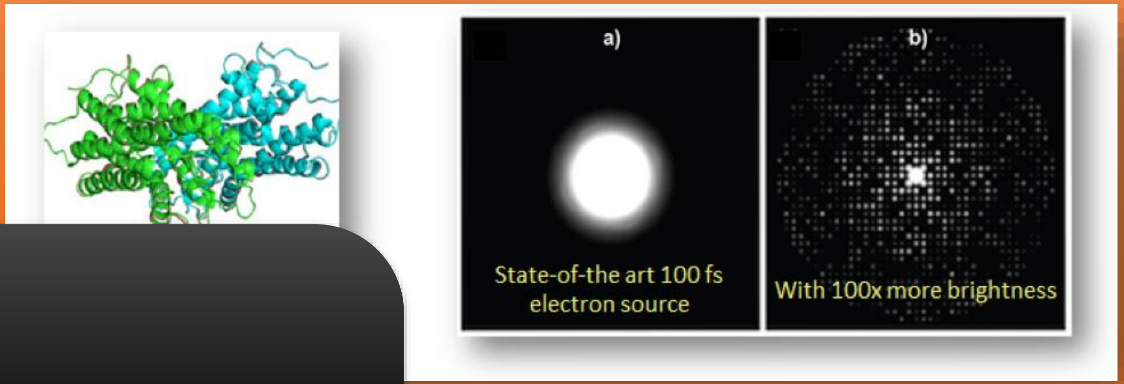
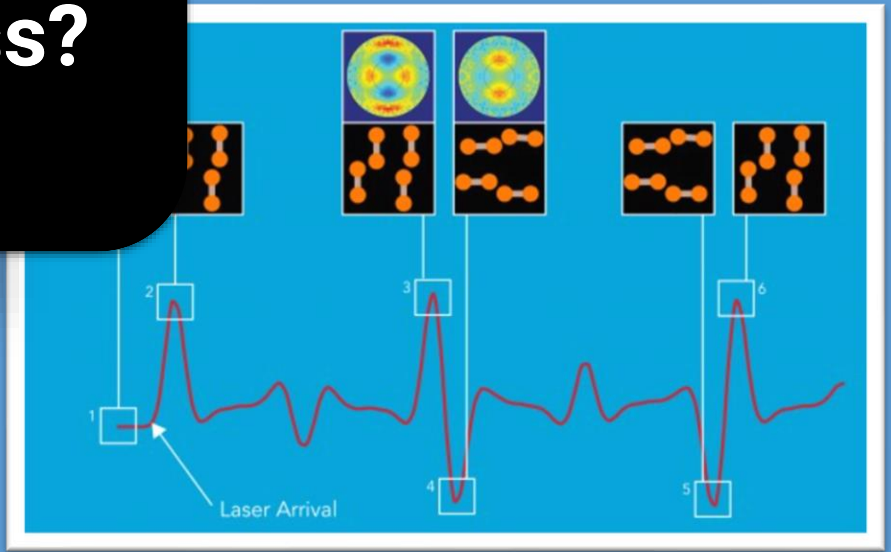
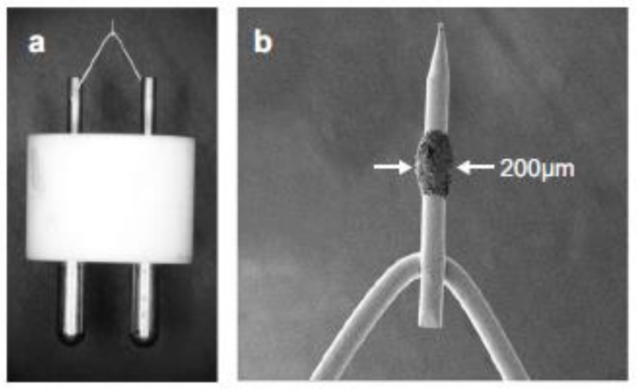




What effects limit source brightness?

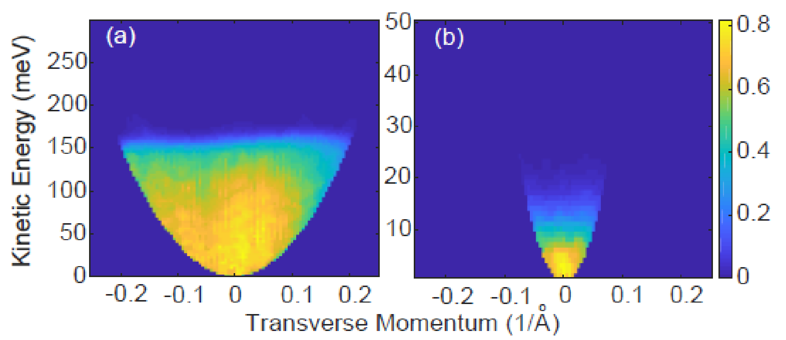
(Some) Limits to Photoinjector Brightness

Source Size
(Also, in Longitudinal Axis)



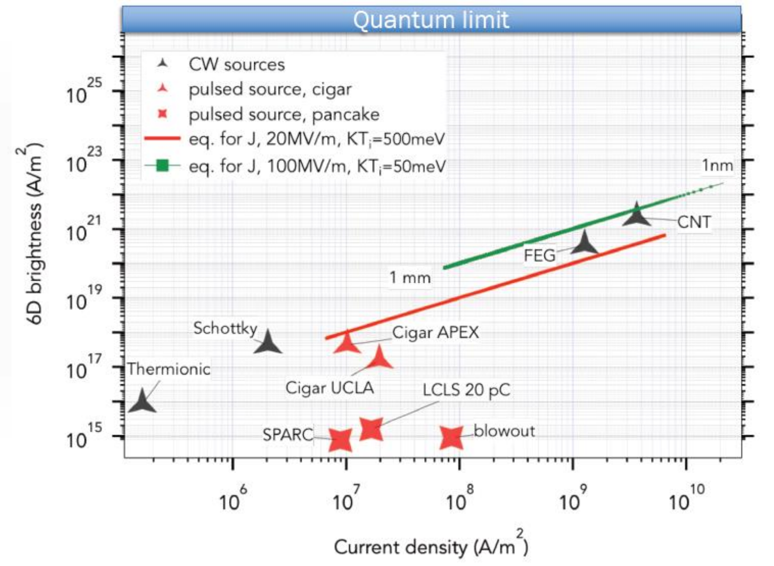
Feist, A., et al. (2017). *Ultramicroscopy*, *176*, 63–73.

Initial (Stochastic) Momentum Spread
(Also, in Longitudinal Axis)



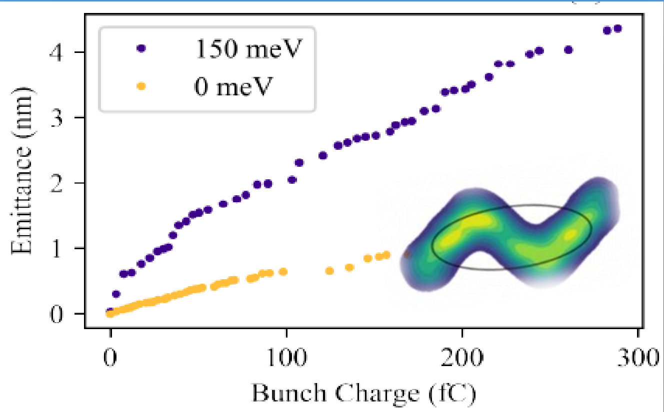
Karkare, S., Adhikari, G., Schroeder, W. A., Nangoi, J. K., Arias, T., Maxson, J., & Padmore, H. (2020). PRL, *125*(5), 054801

Extraction Limits



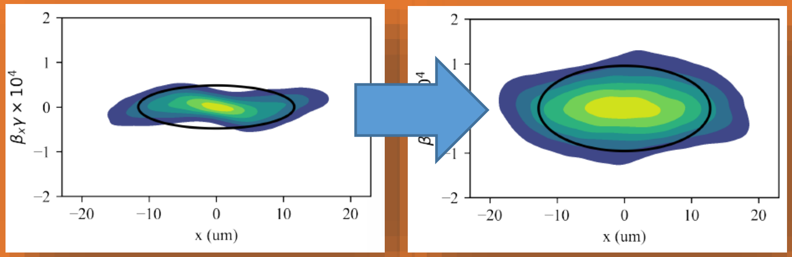
Filippetto, D., Musumeci, P., Zolotorev, M., & Stupakov, G. (2014). PR-STAB, *17*(2), 024201

Nonlinear Space Charge



Pierce, C. M., Andorf, M. B., Lu, E., et al. (2020). PRAB, *23*(7), 070101

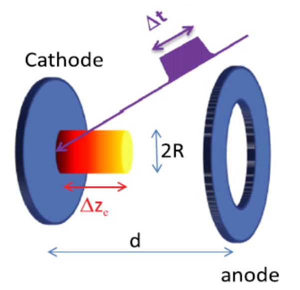
Disorder Induced Heating



Pierce, C. M., Andorf, M. B., Lu, E., et al. (2020). PRAB, *23*(7), 070101

Gordon, M., van der Geer, S. B., Maxson, J., & Kim, Y.-K. (2021). *ArXiv:2104.07797 [Physics]*.

Maxson, J. M., Bazarov, I. V., Wan, W., Padmore, H. A., & Coleman-Smith, C. E. (2013). *New Journal of Physics*, *15*(10), 103024



CIGAR

$$J_{sat,2D} = \frac{I_0}{9\pi}\sqrt{\frac{2}{R}}\left(\frac{eE_0}{mc^2}\right)^{\frac{3}{2}}$$

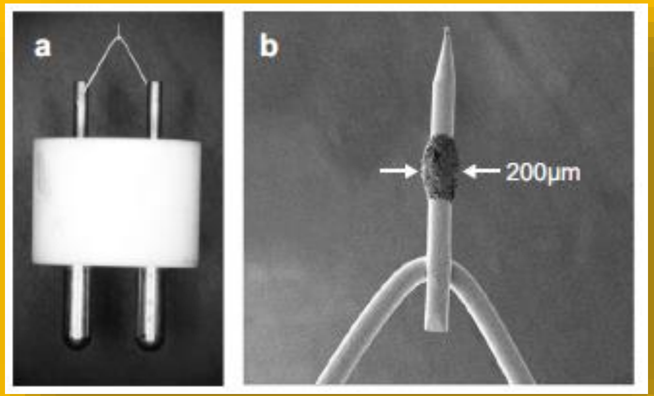
PANCAKE

$$B_{max} = \frac{mc^2\epsilon_0 E}{2\pi kT}$$

Bazarov, I. V., Dunham, B. M., & Sinclair, C. K. (2009). PRL, *102*(10), 104801.

(Some) Limits to Photoinjector Brightness

Source Size (Also, in Longitudinal Axis)



Feist, A., et al. (2017). *Ultramicroscopy*, *176*, 63–73.

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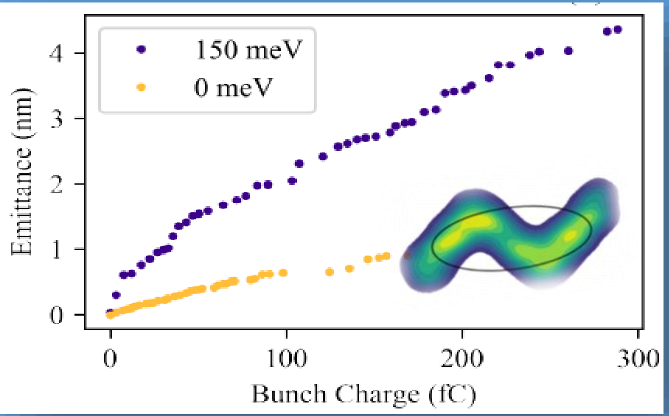

Pierce, C. M., Andorf, M. B., Lu, E., et al. (2020). PRAB, *23*(7), 070101

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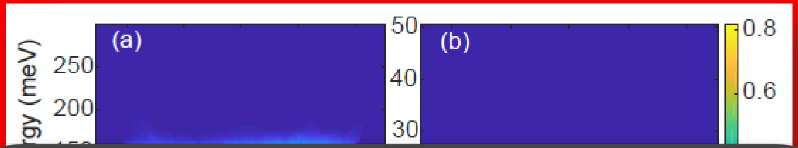

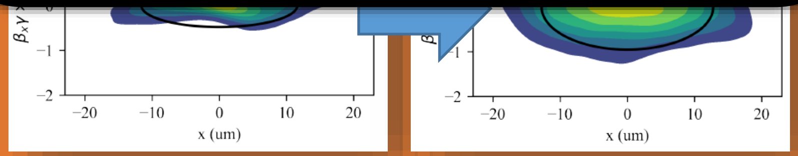

If we don't require high charge, several of these go away!

Pierce, C. M., Andorf, M. B., Lu, E., et al. (2020). PRAB, *23*(7), 070101

Gordon, M., van der Geer, S. B., Maxson, J., & Kim, Y.-K. (2021). *ArXiv:2104.07797 [Physics]*.

Maxson, J. M., Bazarov, I. V., Wan, W., Padmore, H. A., & Coleman-Smith, C. E. (2013). *New Journal of Physics*, *15*(10), 103024

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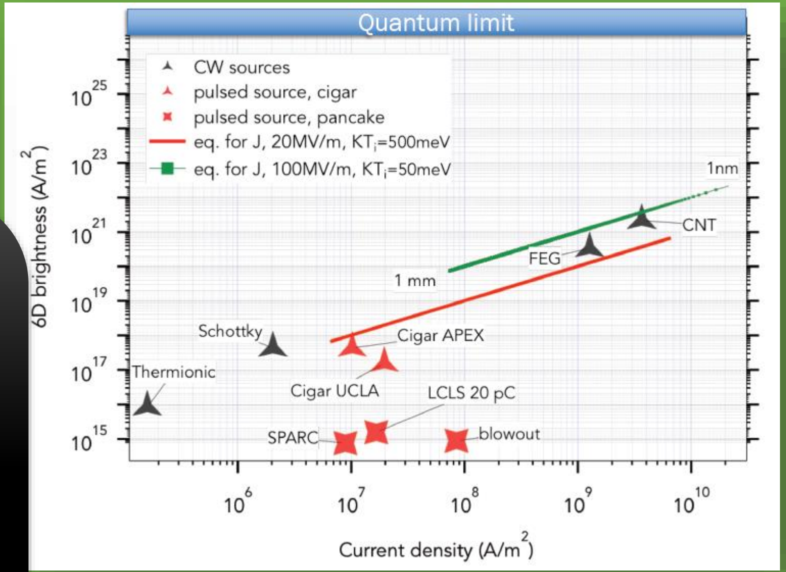
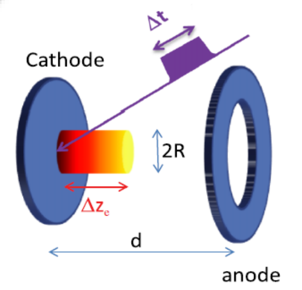


Filippetto, D., Musumeci, P., Zolotorev, M., & Stupakov, G. (2014). PR-STAB, *17*(2), 024201



CIGAR

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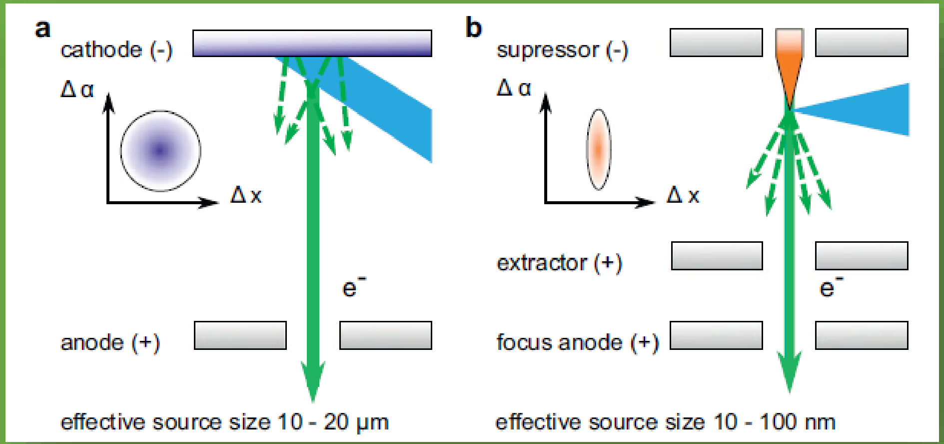
PANCAKE

$$B_{max} = \frac{mc^2\epsilon_0 E}{2\pi kT}$$

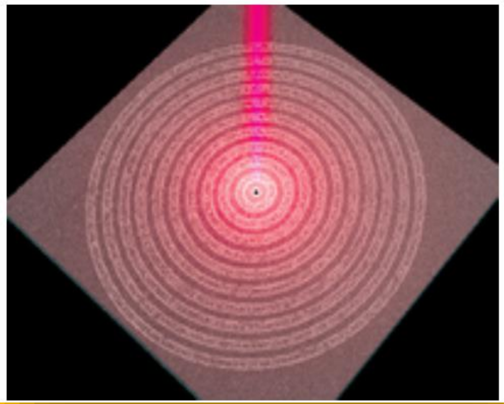
Bazarov, I. V., Dunham, B. M., & Sinclair, C. K. (2009). PRL, *102*(10), 104801.

Combining Benefits of Tip and Flat Emitters

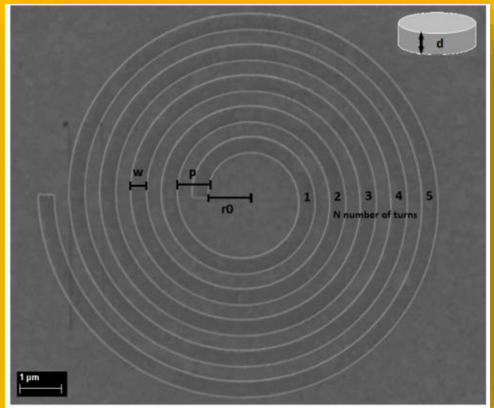
Size – Angular Spread Tradeoff



Feist, A., et al. (2017). *Ultramicroscopy*, *176*, 63–73.

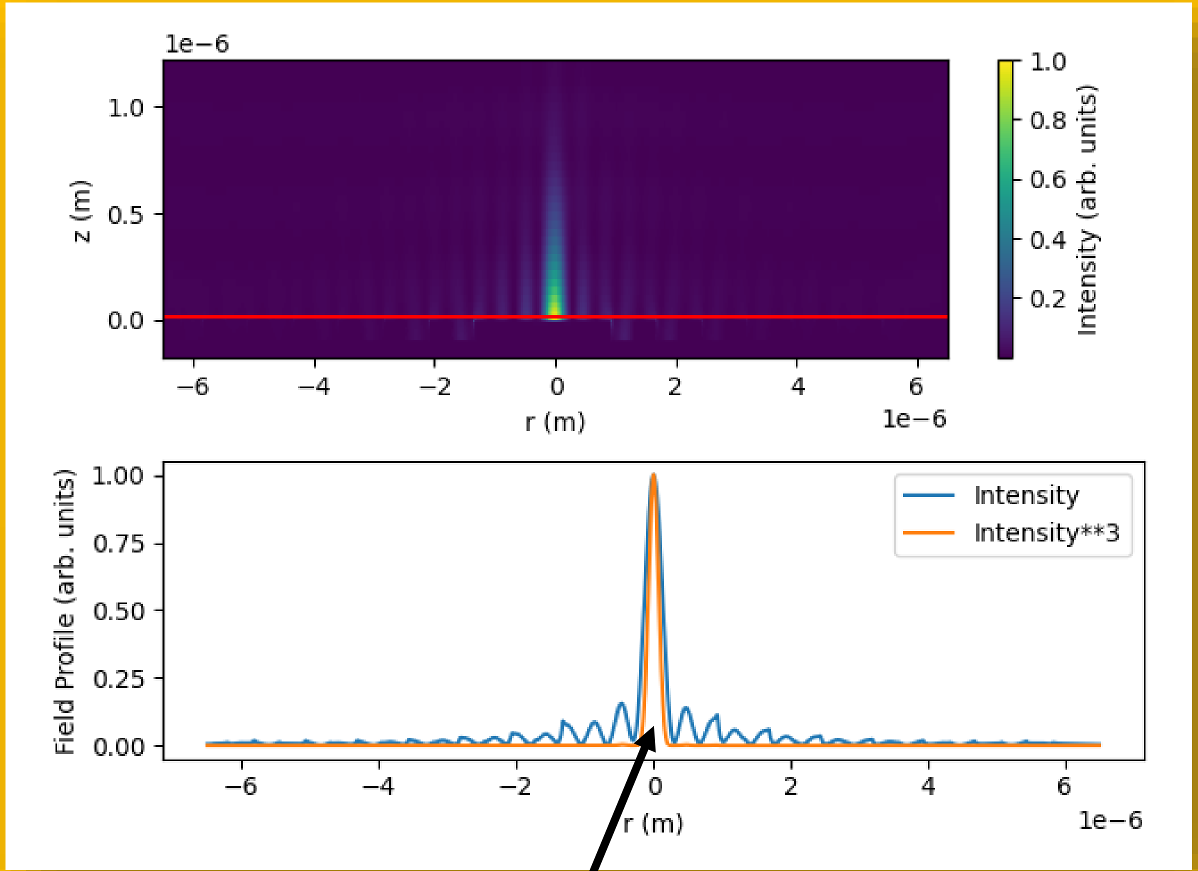


Filippetto, D. (2018, October). Photocathode Physics for Photoinjectors, New Mexico.



Durham, D. B., Riminucci, F., Ciabattini, F., Mostacci, A., Minor, A. M., Cabrini, S., & Filippetto, D. (2019. *PRA*, *12*(5), 054057.

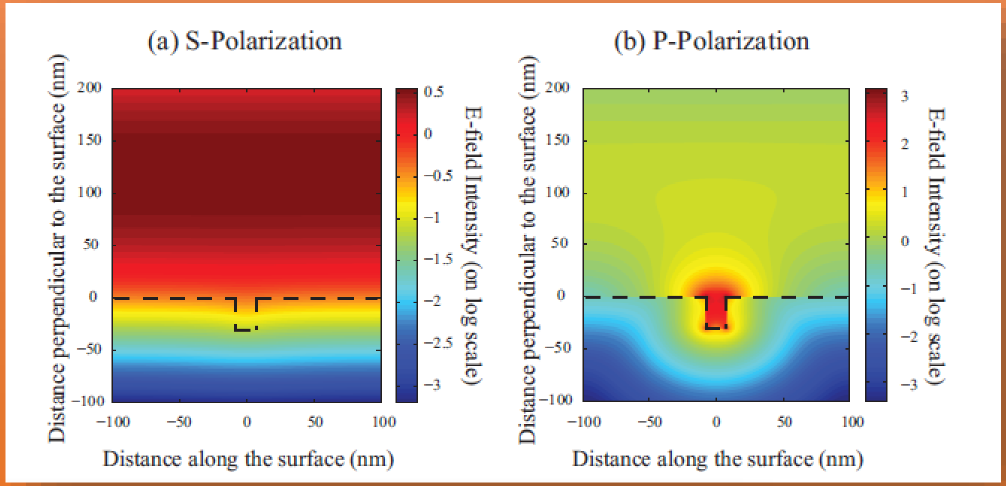
Plasmonic Lens for Sub-Wavelength Emission on Flat Surface

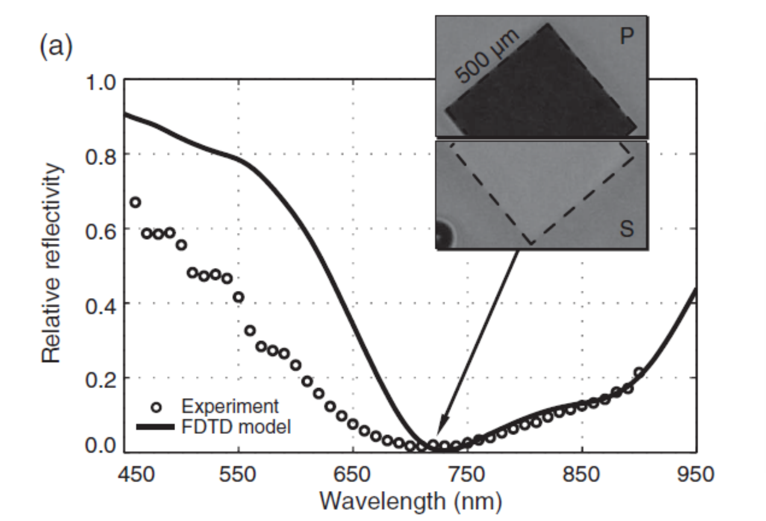


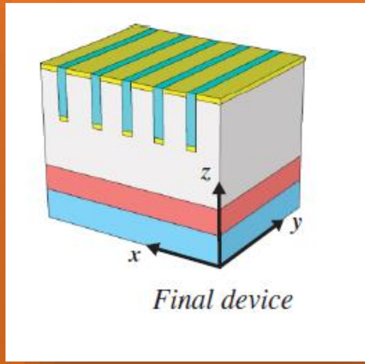
Non-linear photoemission shrinks source size further (estimate ~100nm with practical structures)

Existing Measurements – Nanogrooves

Plasmonic Nearfield Increases Localized Intensity

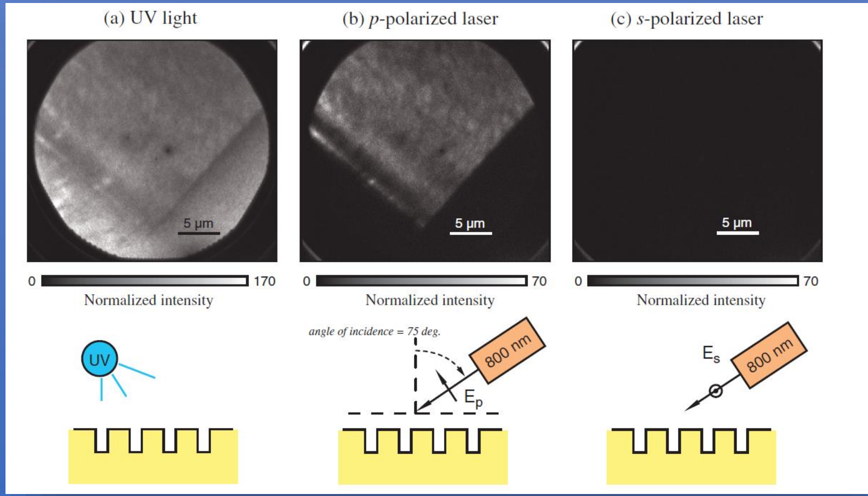


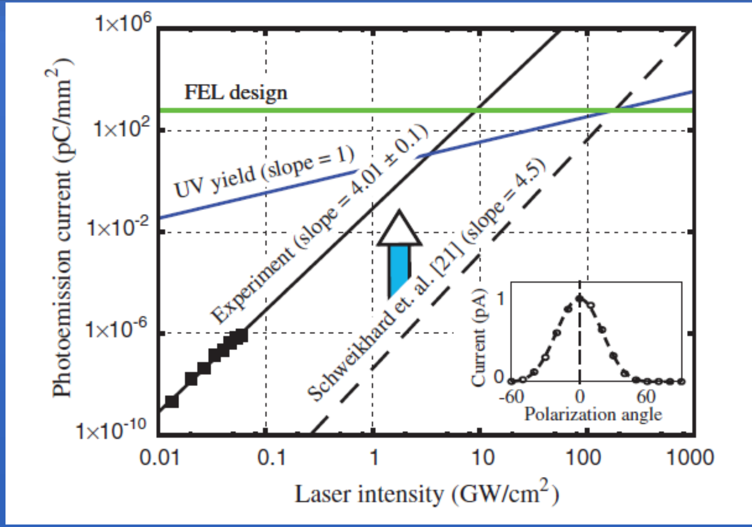




Polyakov, A., et al. (2013). *PRL*, *110*(7), 076802.

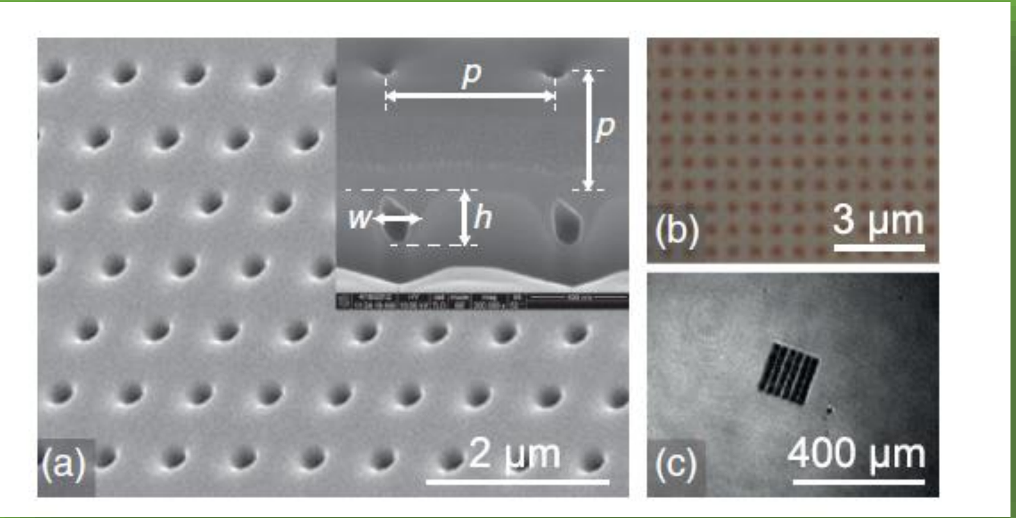
Ultrafast Laser Drives Fourth-Order Photoemission

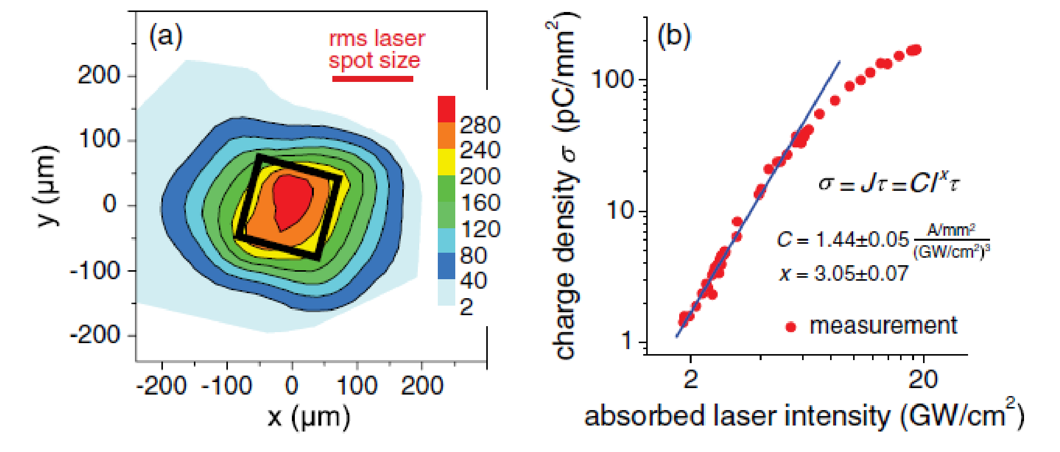




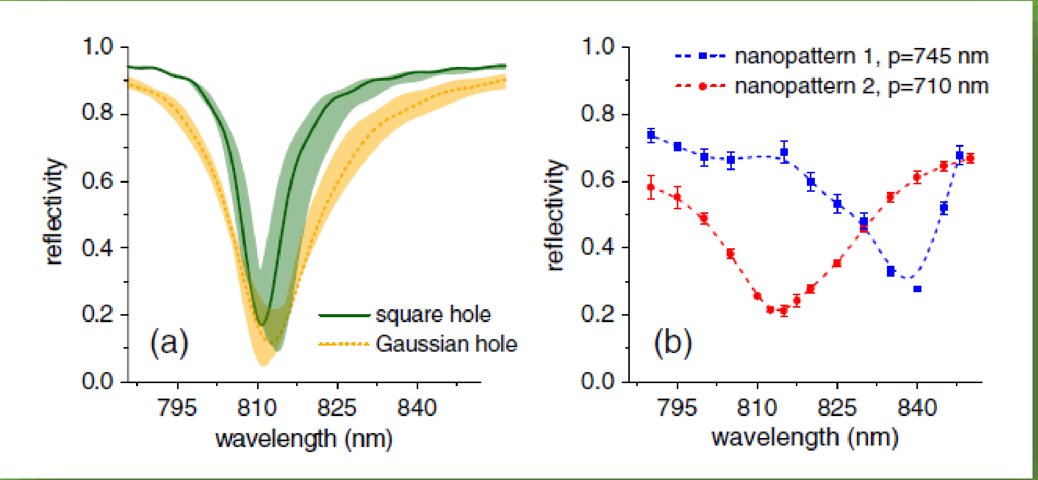
Existing Measurements – Hole Arrays

Achieve Non-linear Photoemission Enhancement from FIB'ed array of holes

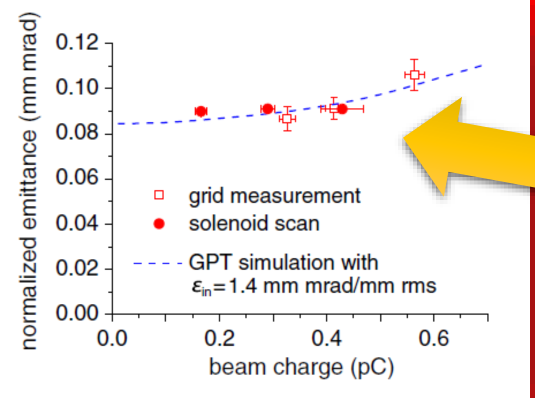




Li, R. K., e al. (2013). *PRL*, *110*(7), 074801.



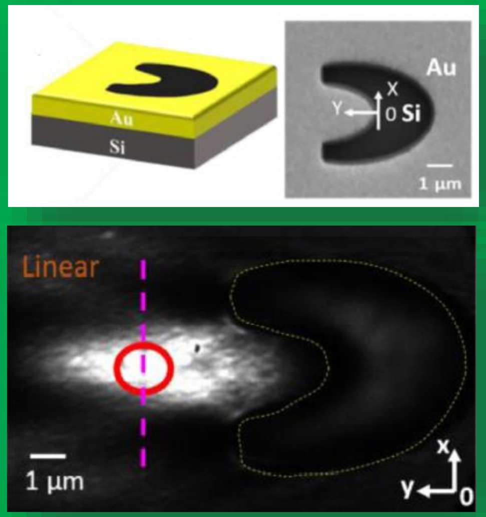
First Emittance Measurements from these Structures



Roughness inflates MTE to 1eV

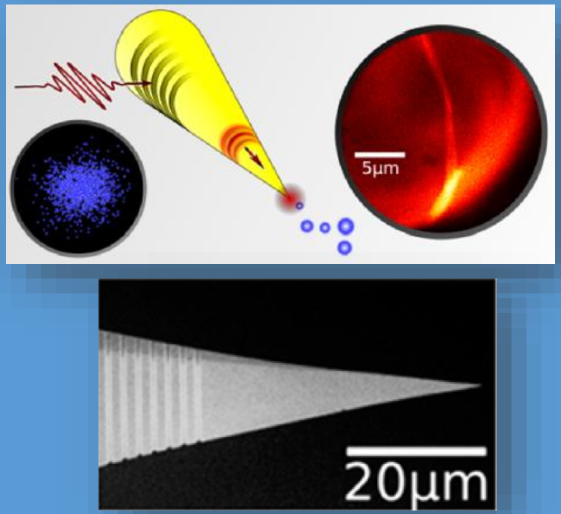
Existing Measurements – A Few Focusing Methods

Oblique Incidence Lens



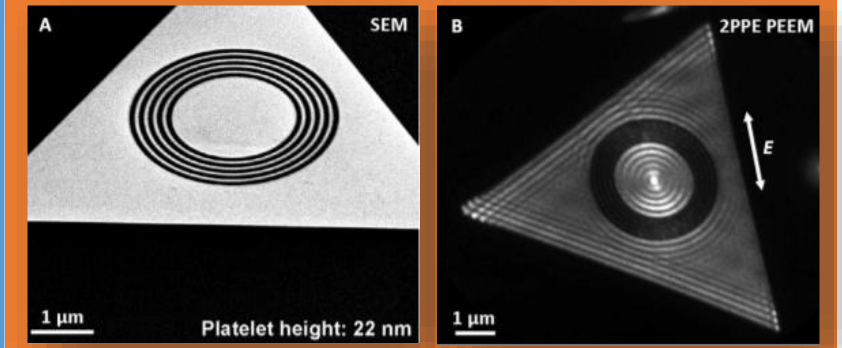
Wang, G., Lang, P., Qin, Y., Ji, B., Song, X., & Lin, J. (2021). *Physical Review B*, *104*(15), 155432

Adiabatic Nanofocusing



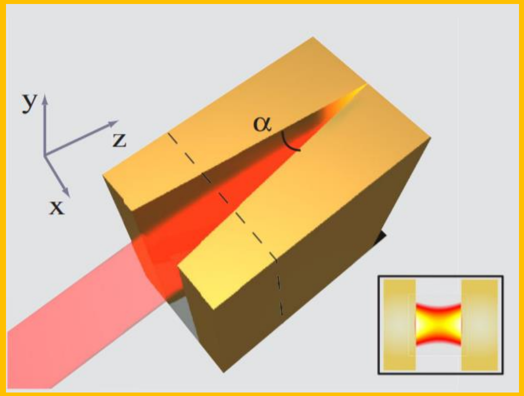
Vogelsang, J., Robin, J., Nagy, B. J., Dombi, P., Rosenkranz, D., Schiek, M., Groß, P., & Lienau, C. (2015). *Nano Letters*, *15*(7), 4685–4691

Bullseye – Concentric Ring Lens



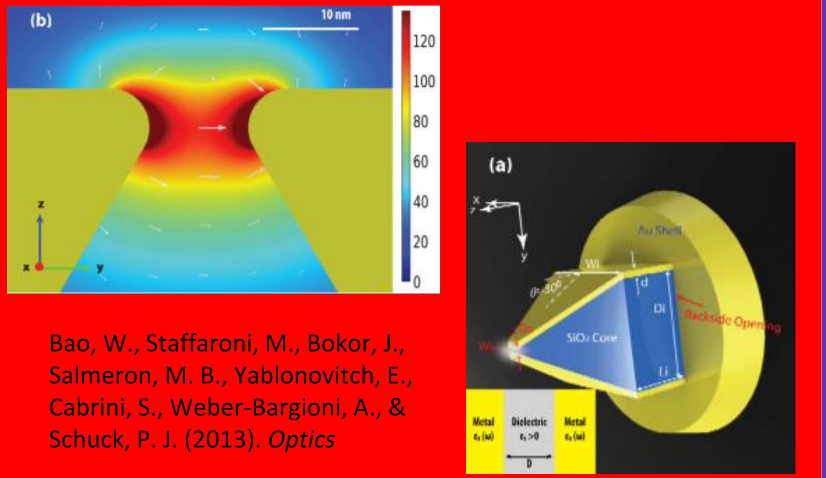
Frank, B., Kahl, P., Podbiel, D., Spektor, G., Orenstein, M., Fu, L., Weiss, T., Horn-von Hoegen, M., Davis, T. J., Meyer zu Heringdorf, F.-J., & Giessen, H. (2017). *Science Advances*, *3*(7), e1700721.

Tapered Waveguide



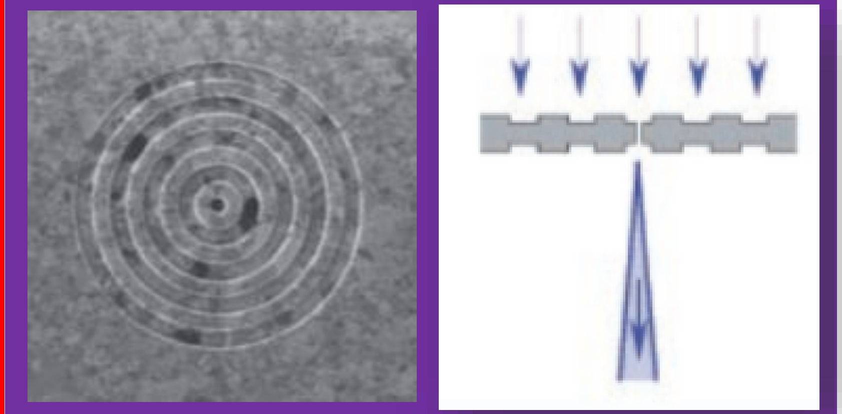
Davoyan, A. R., Shadrivov, I. V., Zharov, A. A., Gramotnev, D. K., & Kivshar, Y. S. (2010). *Physical Review Letters*, *105*(11), 116804.

Campanile Geometry



Bao, W., Staffaroni, M., Bokor, J., Salmeron, M. B., Yablonovitch, E., Cabrini, S., Weber-Bargioni, A., & Schuck, P. J. (2013). *Optics*

Subwavelength Hole Beaming



Lezec, H. J., Degiron, A., Devaux, E., Linke, R. A., Martin-Moreno, L., Garcia-Vidal, F. J., et al. (2002). *Science*, *297*(5582), 820–822.

Nanogroove Sample

Template Stripping Fabrication

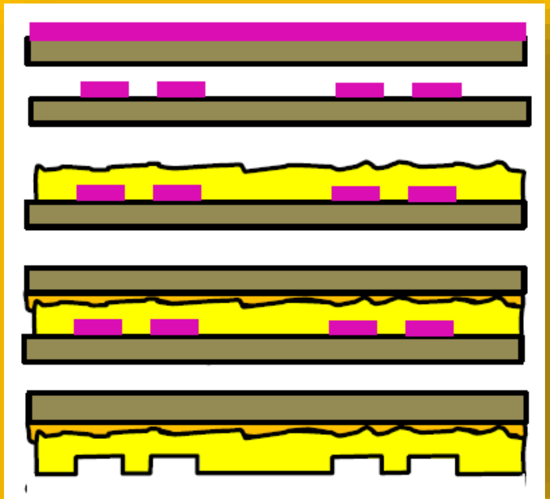
Deposit e-beam resist

Expose Pattern

Evaporate Gold

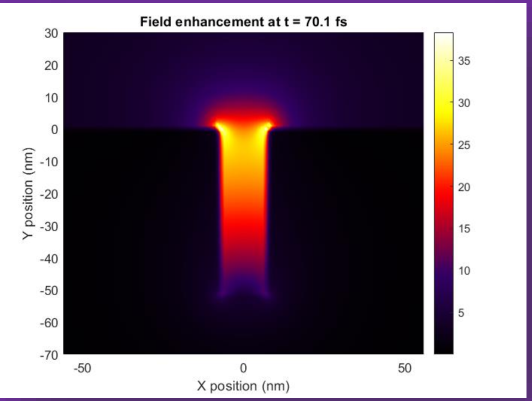
Attach to Substrate with Epoxy

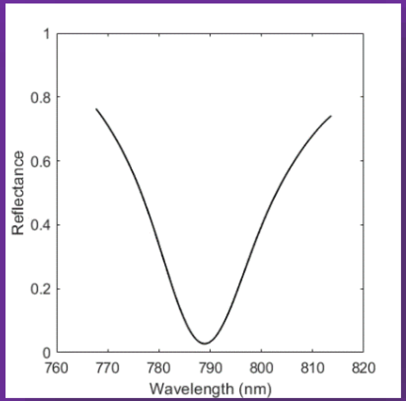
Peel off of Template



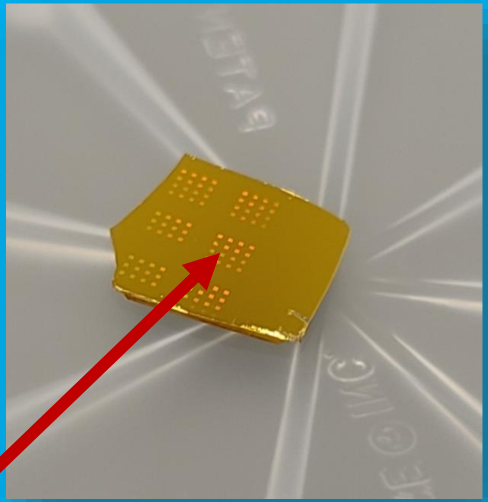
Filippetto, D. (2018, October). Photocathode Physics for Photoinjectors, New Mexico.

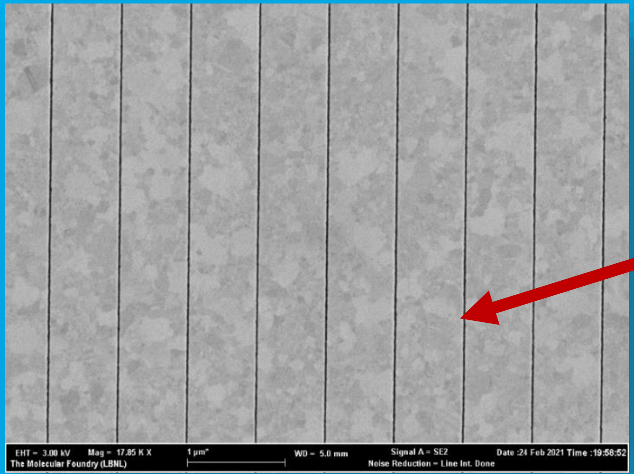
Simulated Enhancement / Absorption

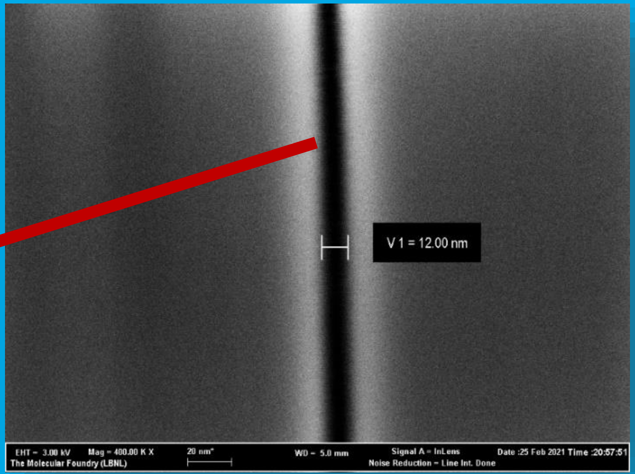




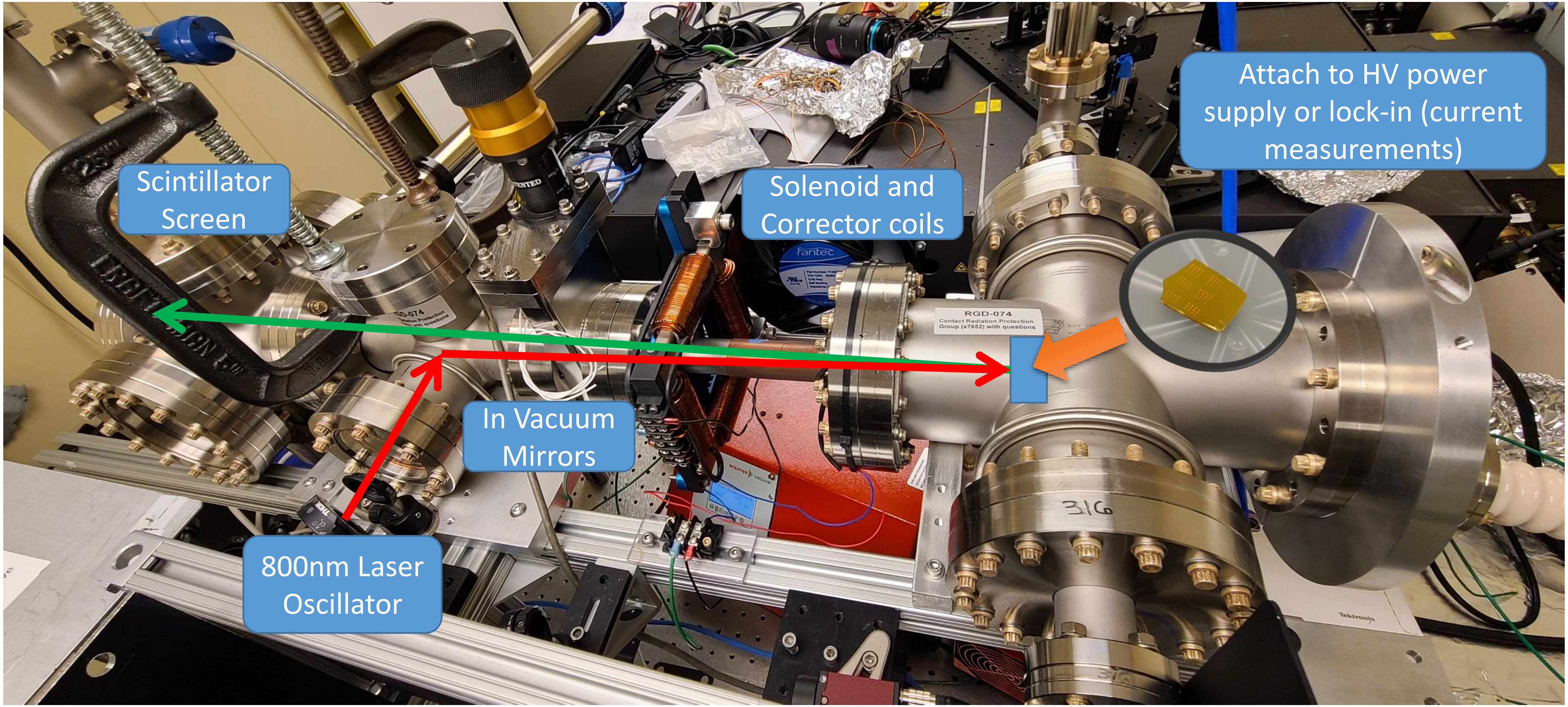
Successfully Prepared Samples



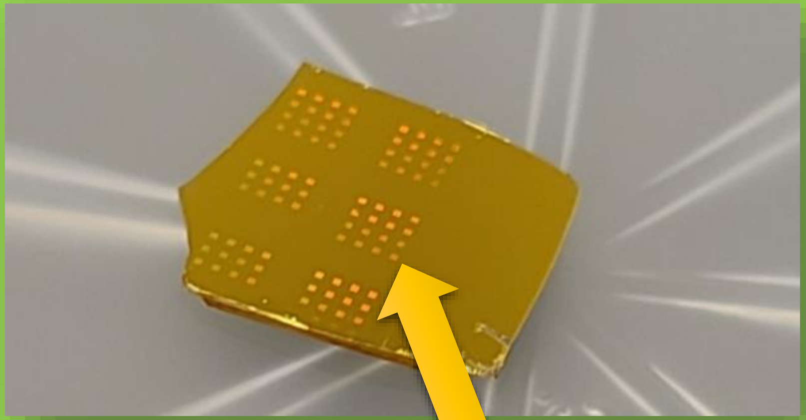




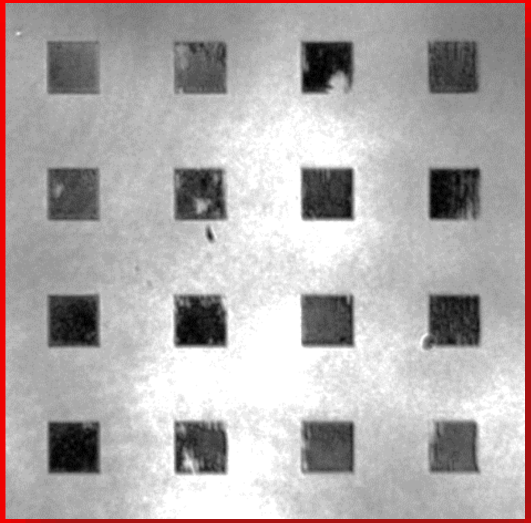
LBL Low Voltage Gun



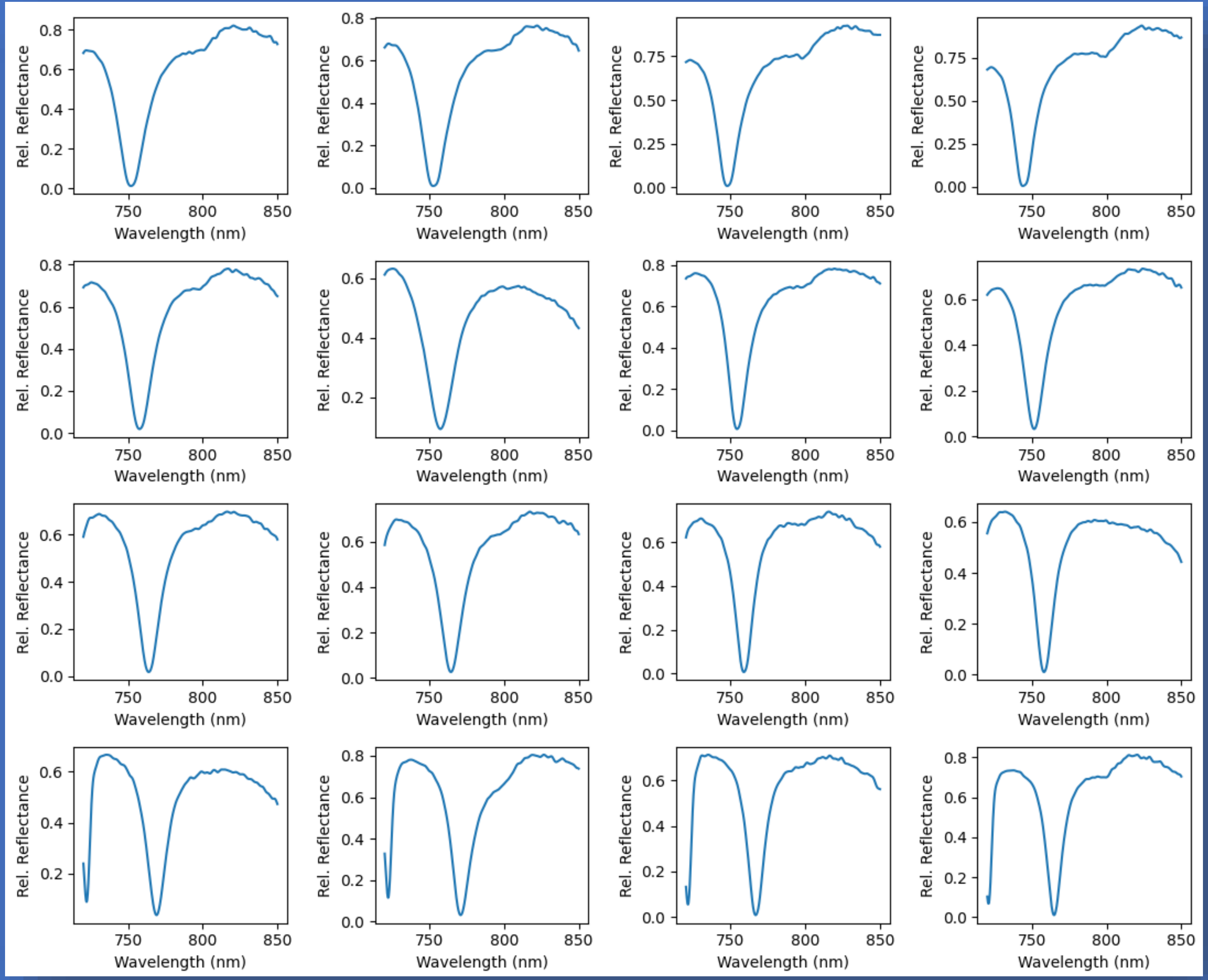
Nanogrooves – Optical Measurements



Reflection Mode Imaging

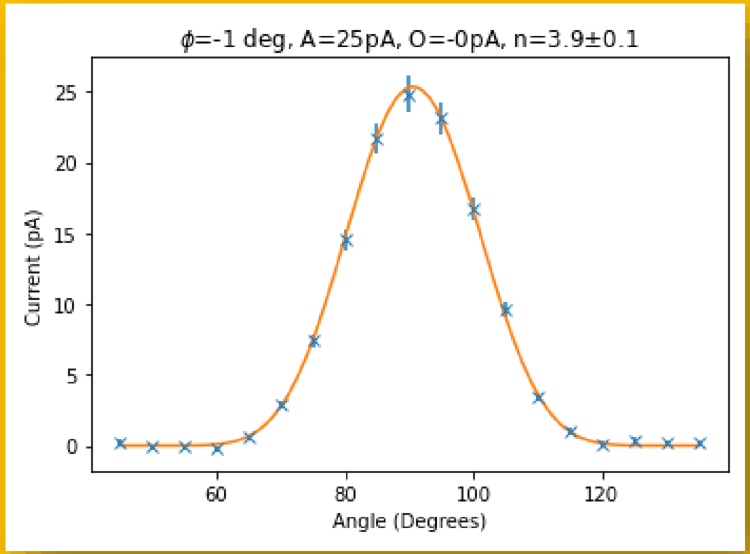


Reflection Spectroscopy

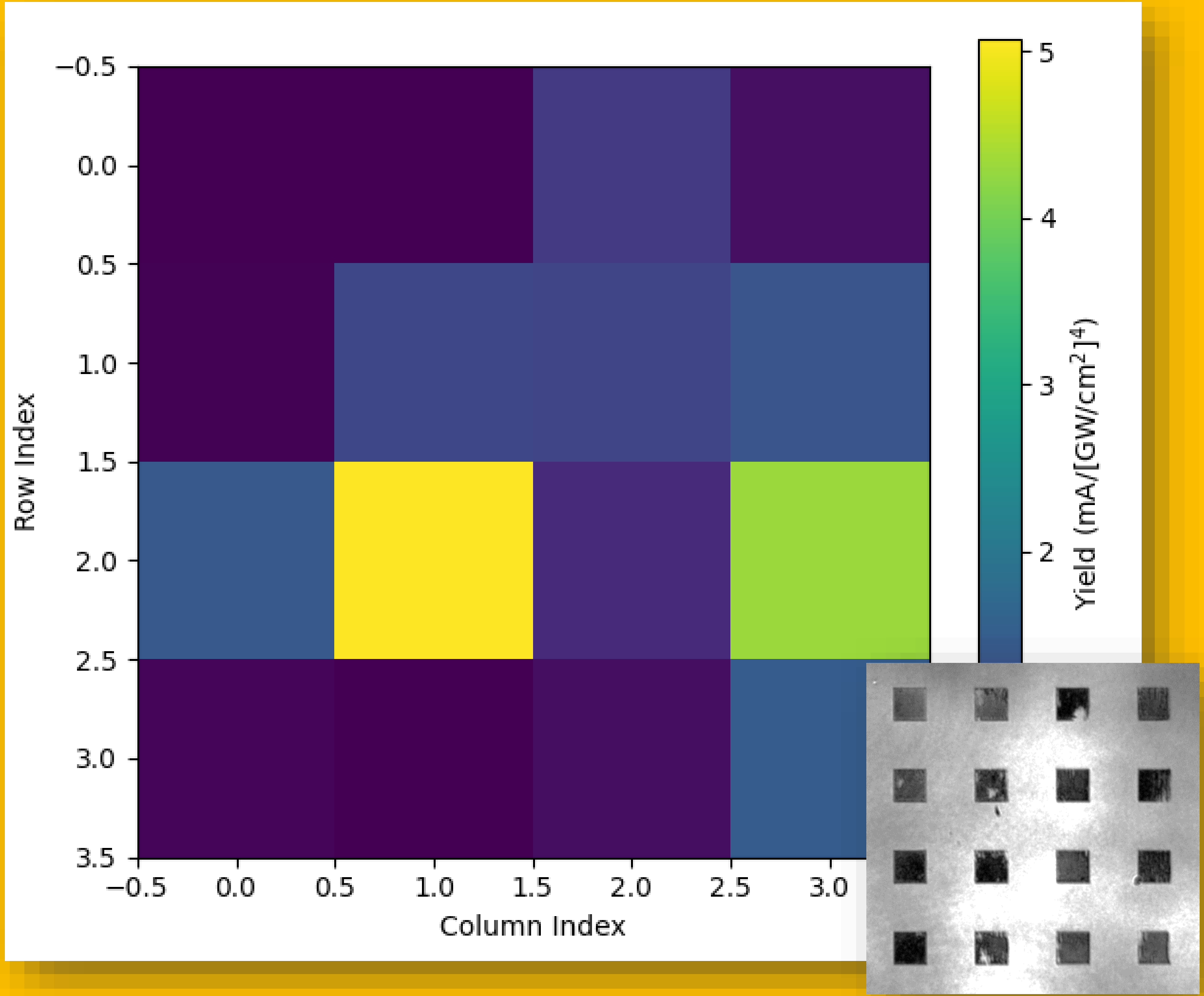


Flat Cathodes

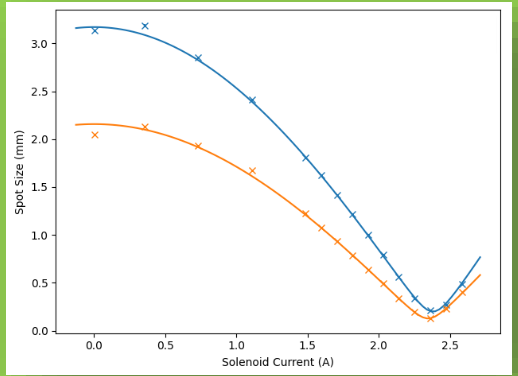
Polarization Dependance

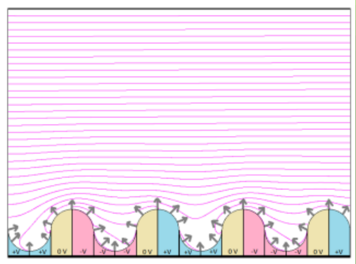


Power Scans – Nonlinear Current Characterization



Preliminary Emittance Measurement

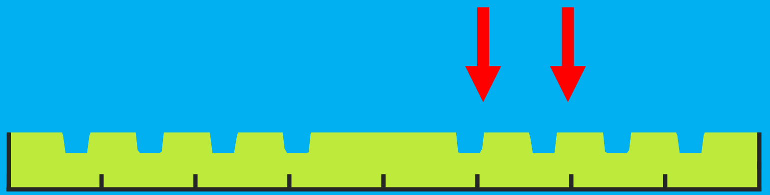




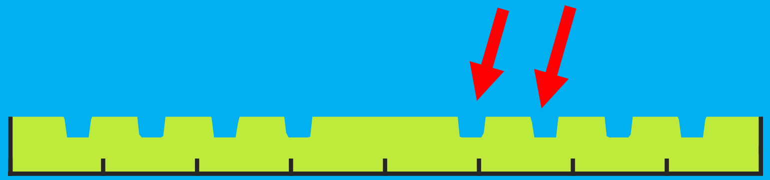
Gevorkyan, G. S., et al. (2018). *PRAB*, *21*(9), 093401.

Spiral Cathodes for Flat Nanoemitters

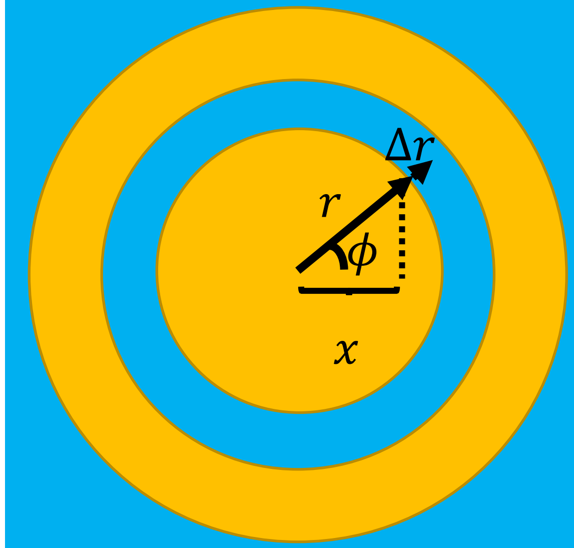
Grating Tilt Compensation



Start from normal-incidence structure



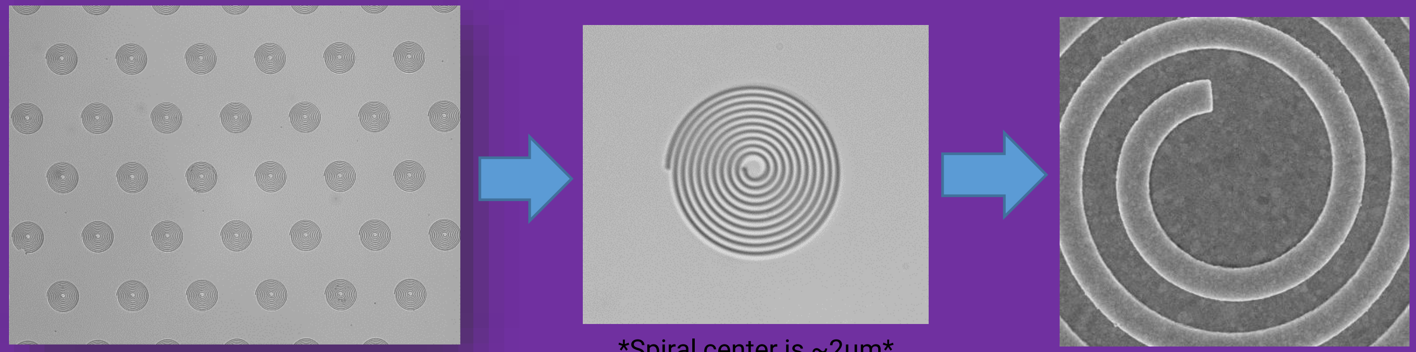
Tilted illumination -> arrival time delay



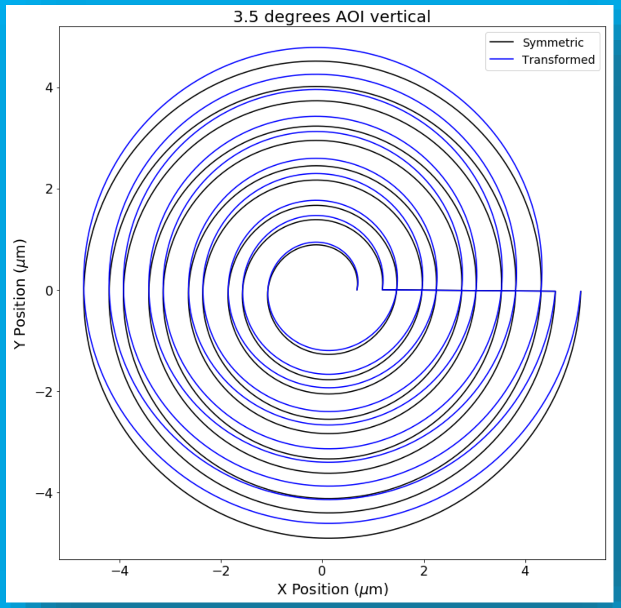
$$x' = x + x\sin(\theta_0)\left(\frac{\lambda_{sp}}{\lambda_0}\right)\cos(\phi)$$

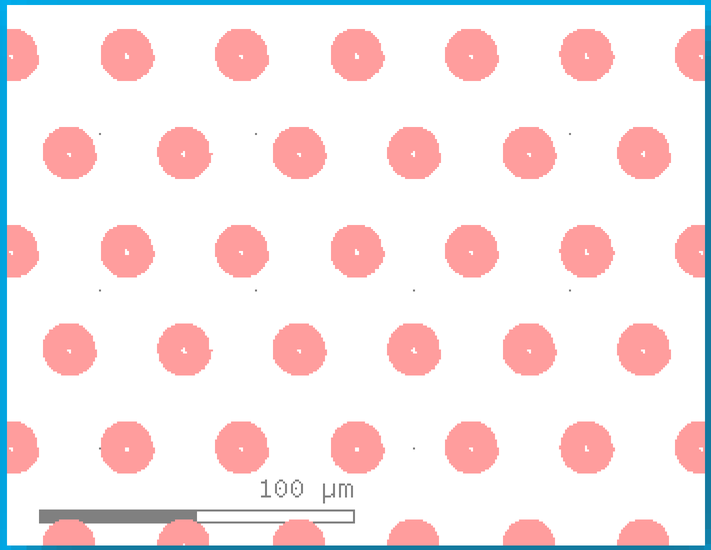
$$y' = y + x\sin(\theta_0)\left(\frac{\lambda_{sp}}{\lambda_0}\right)\sin(\phi)$$

Lift-off Fabricated Spirals



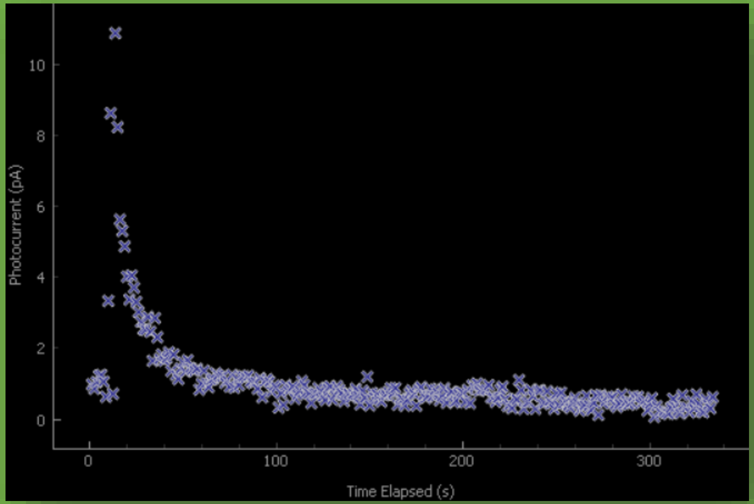
Spiral center is ~2μm

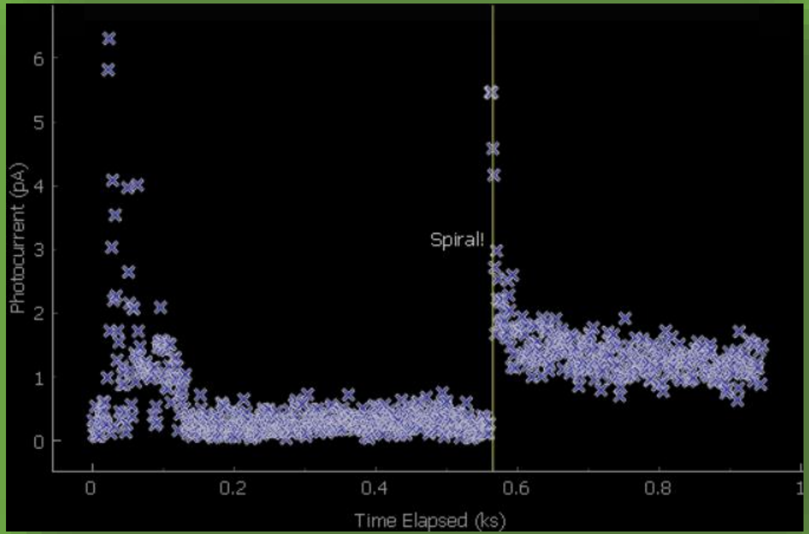




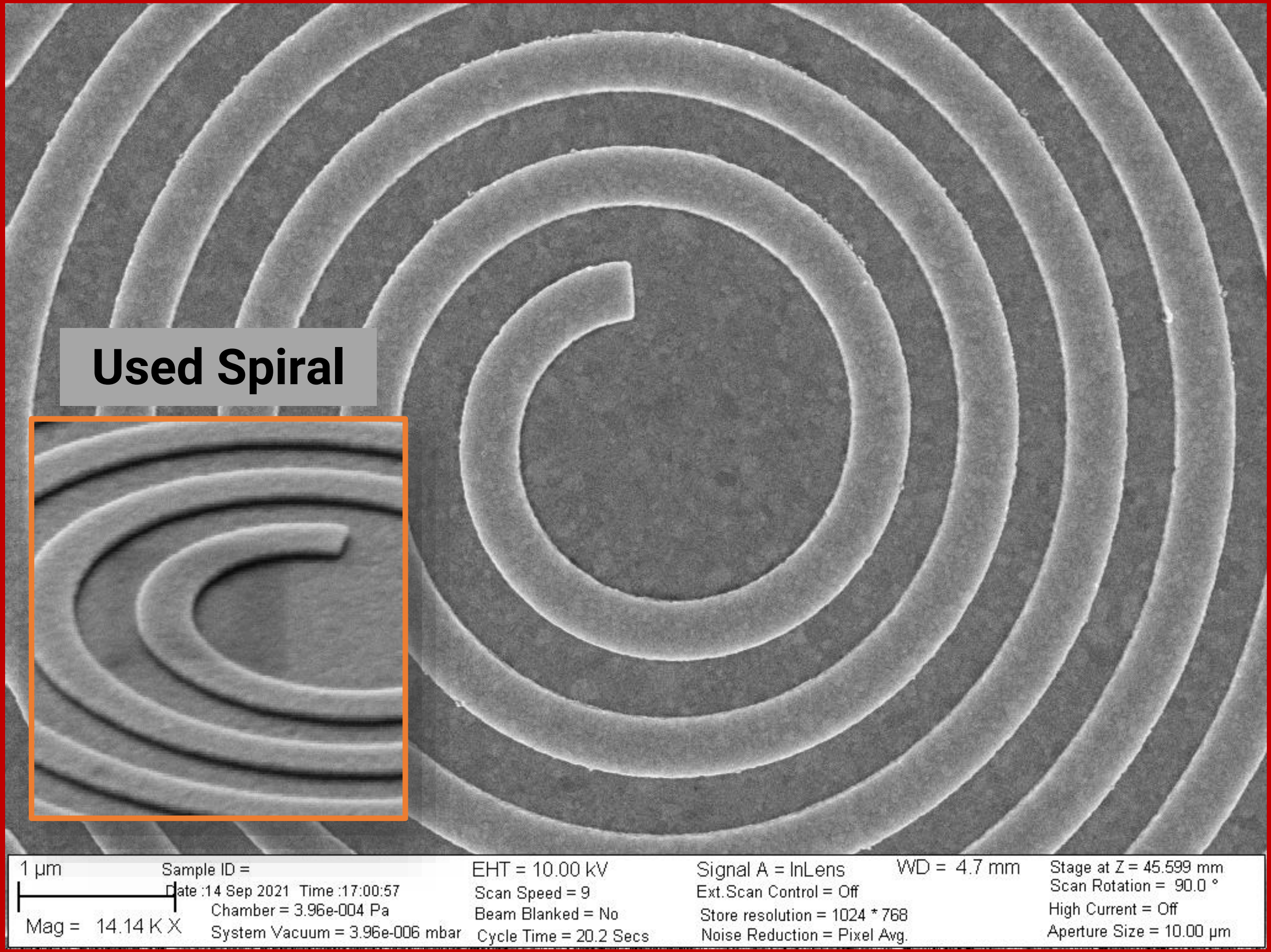
“Self Cleaning” Emission from edges

“Spikey” Current Behavior

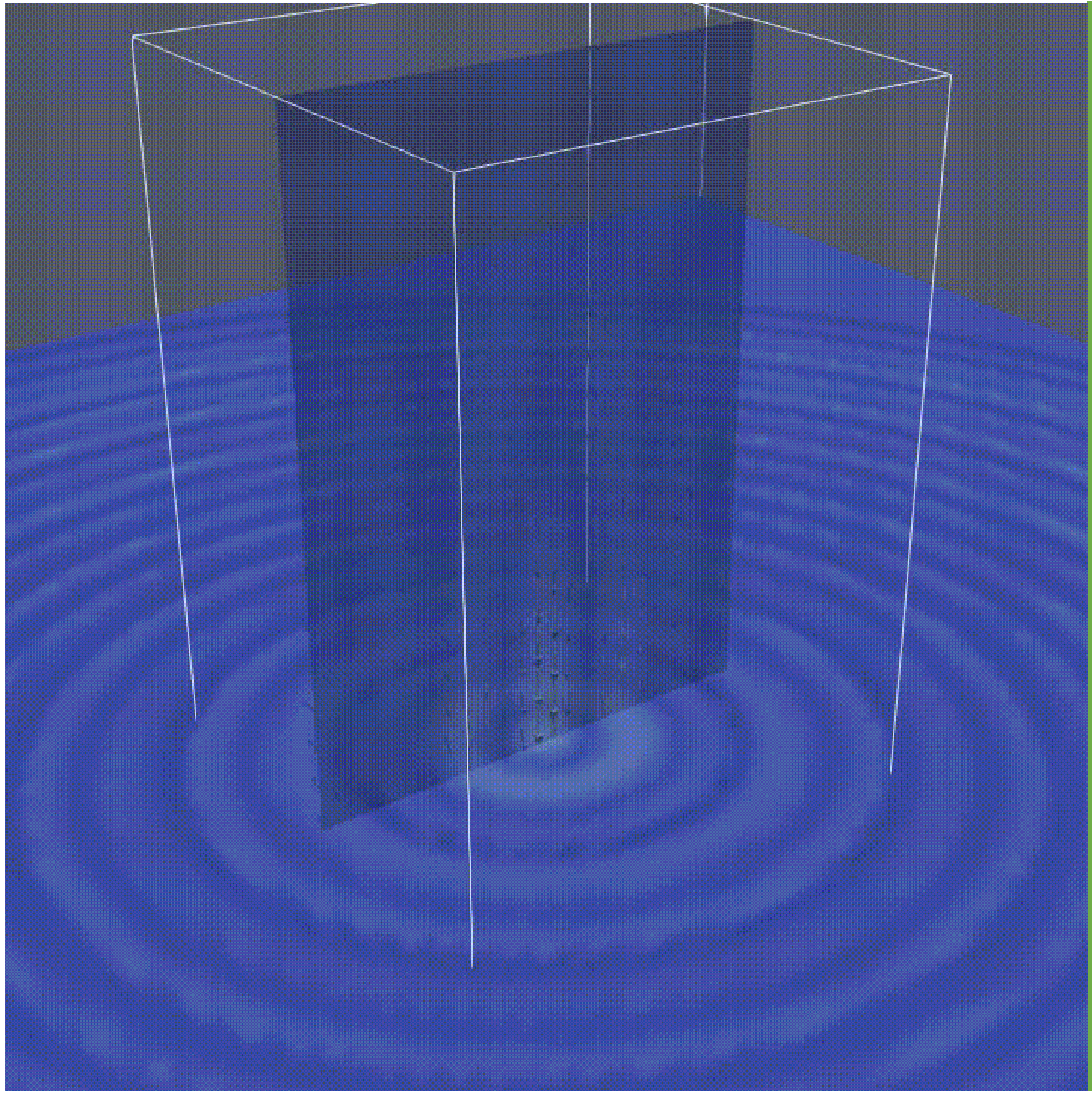




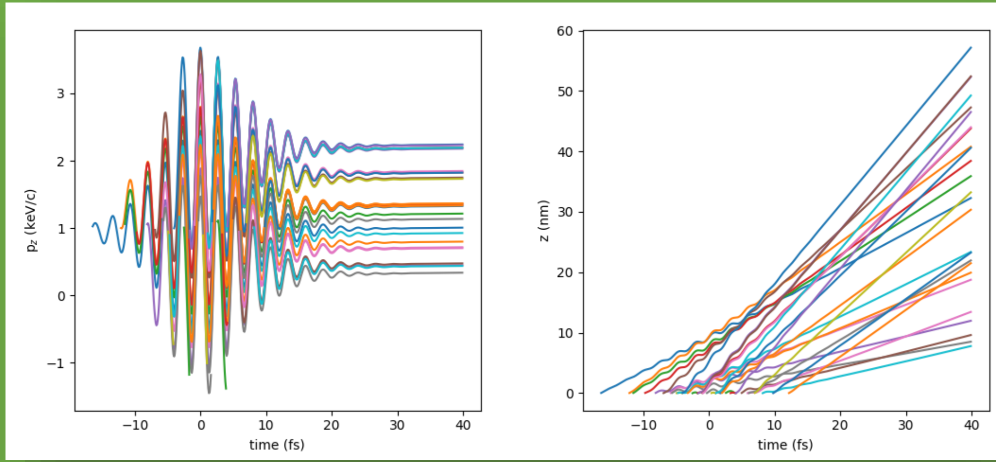
Micrograph Showing Rough Edges on Unused Spiral



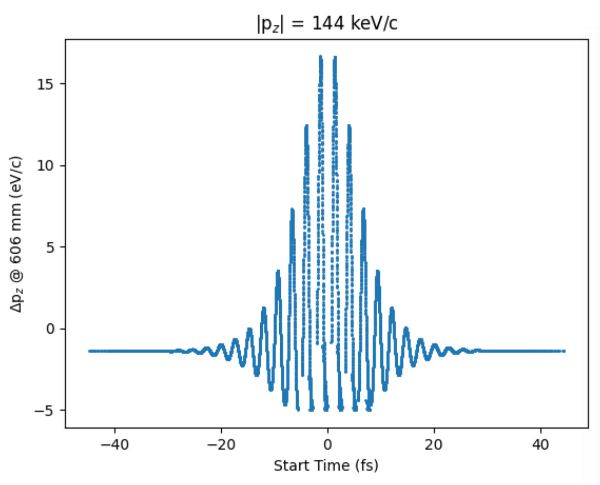
Effect of Nearfields on Photoemitted Electrons

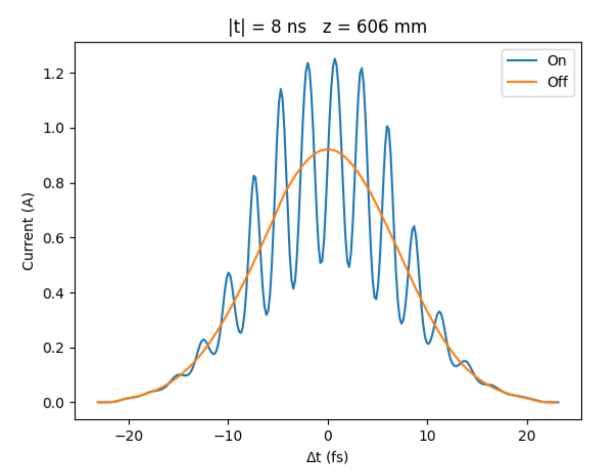


Nearfield Confers Phase Dependent Energy



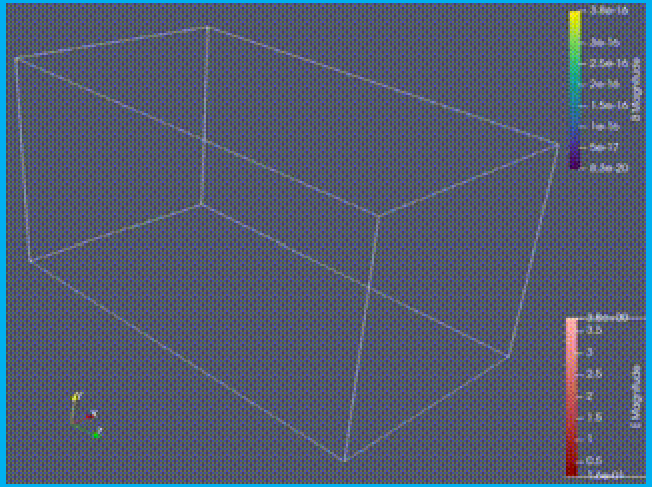
Potential Applications in Attosecond Physics?



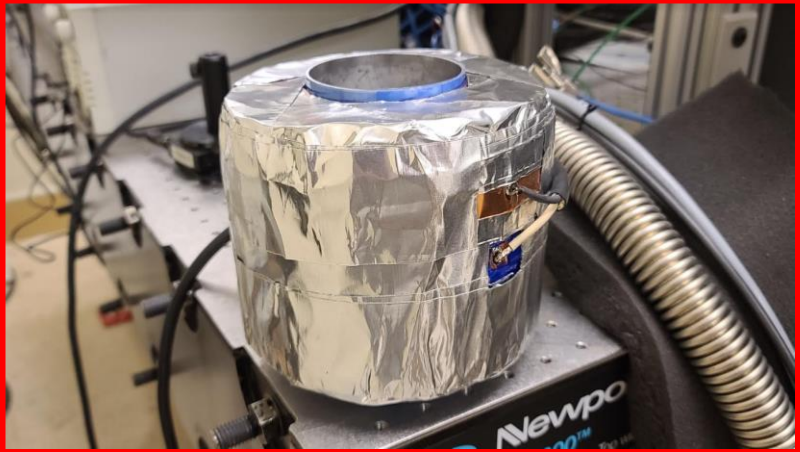


Future Work

Nearfields for Control of Relativistic Beams



Upgrading Beamline for Studying Nanoemitters



Fabrication of Samples with Improved Surface Roughness