Emittance Measurement of a Nanostructured Strong-Field Cathode

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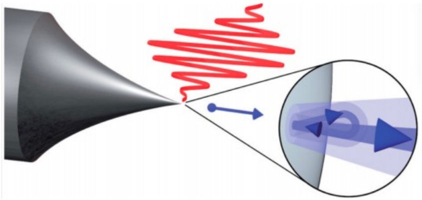
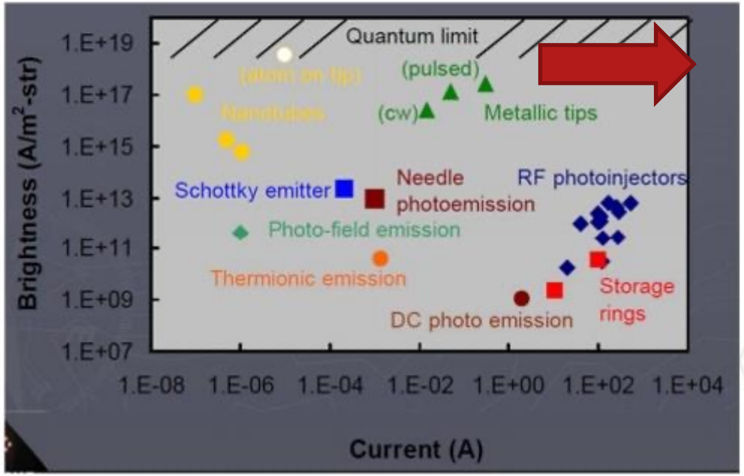
Outline of presentation

1. Motivations & background
2. Cathode fabrication
3. Characterization incl. emittance measurement
4. Future work & conclusions

Motivation

- National Science Foundation Center for Bright Beams (NSF CBB) exploring limits of electron beam brightness for many applications
  - Free electron lasers, ultrafast electron diffraction, advanced accelerating structures, etc.
- One route to increase initial brightness at cathode via smaller laser spot size
- Particularly here interested in engineering cathodes to reduce area of emission (example of nanotip below)
- Charge extracted small due to damage at higher intensity



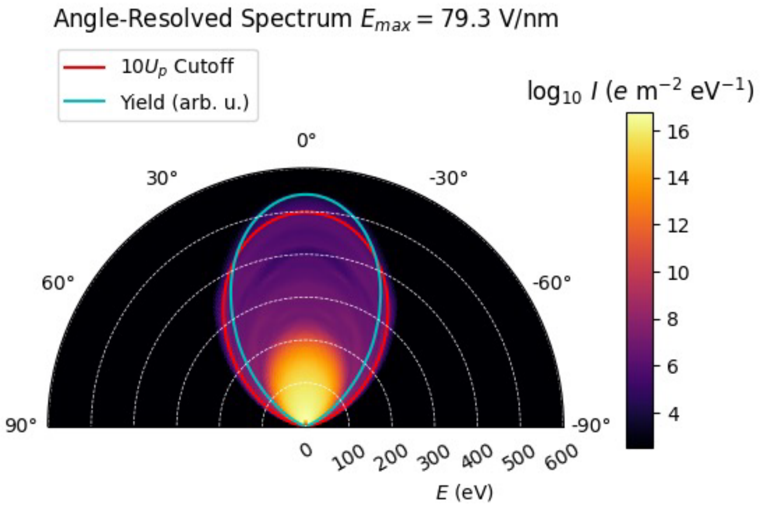


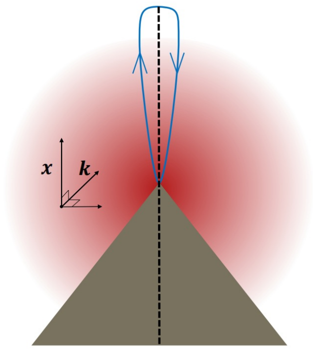
From C. Brau

M. Kruger, et al. New Journal of Physics 14, 085019 (2012).

Background

- Inspired by nanotips used for electron microscopy we want to make higher current
- Projected tip forms nanoblade, allowing for higher current extraction based on increased illumination and higher damage threshold from higher laser fluence
- Like nanotip, nanoblade complicated environment where electron scattering process produces high energy emitted electrons

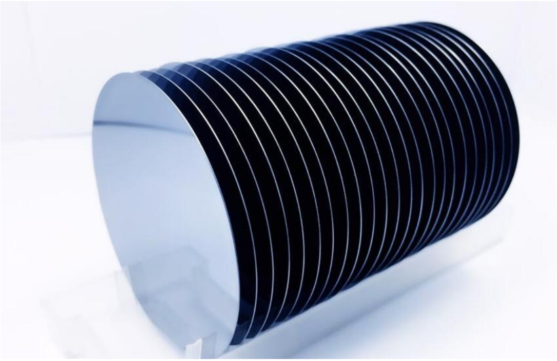


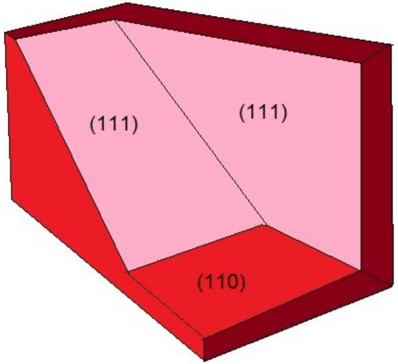


J. Mann, G. Lawler, J. Rosenzweig, *Instruments* **2019**, *3(4), 59;*

Nanofabrication

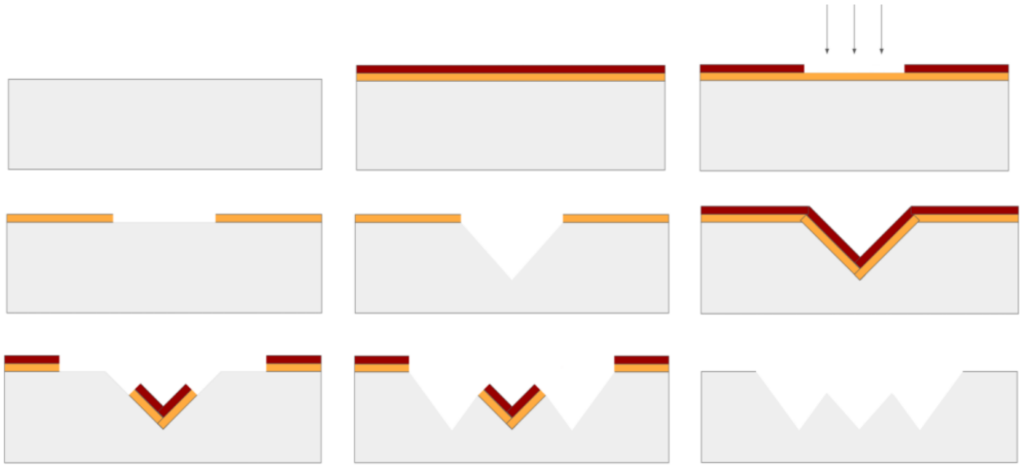
- Nanofabrication here refers procedure to use photolithography and an anisotropic wet etching to produce atomically sharp structures on silicon wafers
- UCLA NanoLab offers unique access to industrial technology to students in an academic environment

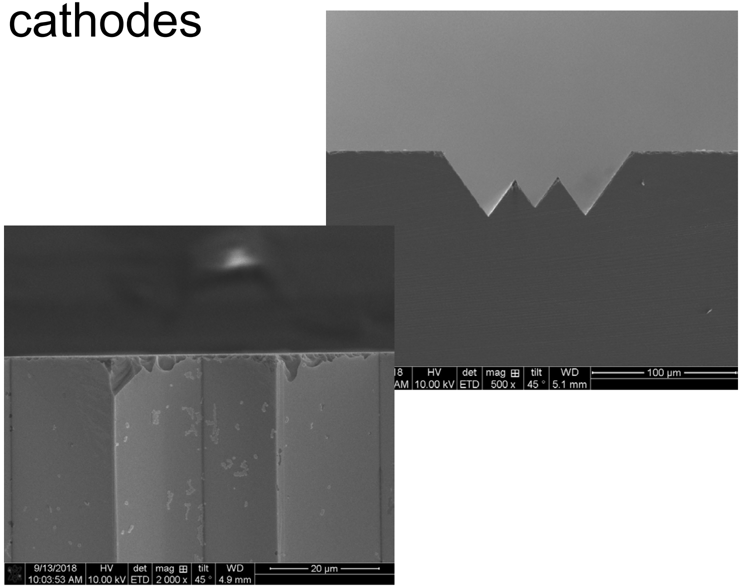




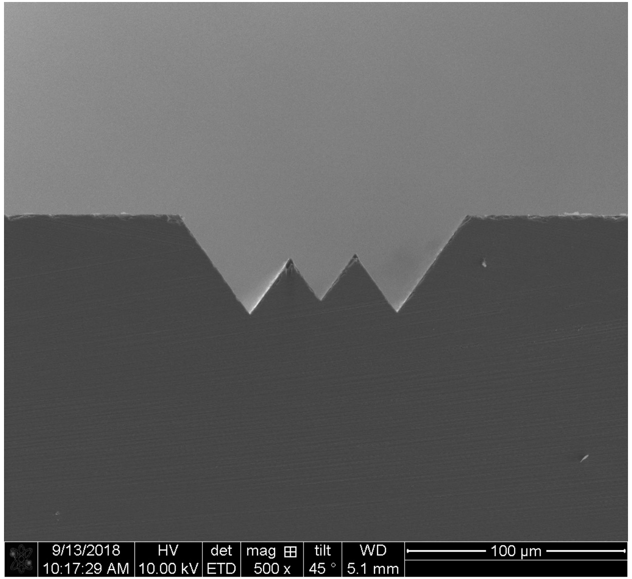
Nanoblade Cathode Fabrication

- Multi-step cathode recipe continually being refined
    - Produces atomically sharp extendend edge (nanoblade)
    - Then coated by metallic layers to produe cathode
- Success rate for fabrication can be improved
- Each silcon wafer produces approx 30-40 useable cathodes

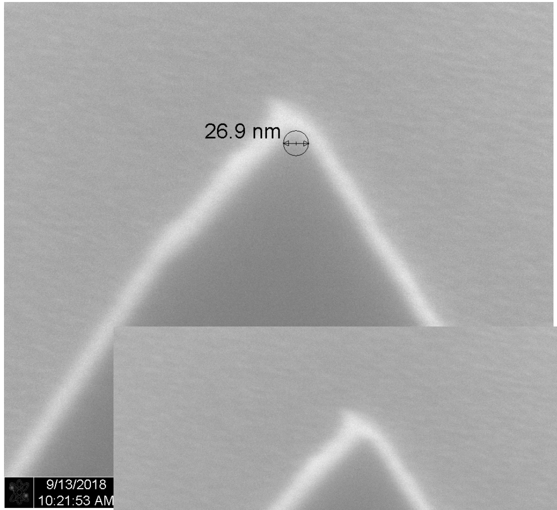




SEM



9/13/2018 10:17:29 AM
HV 10.00 kV
det ETD
mag ⊞ 500 x
tilt 45 °
WD 5.1 mm
100 µm



26.9 nm
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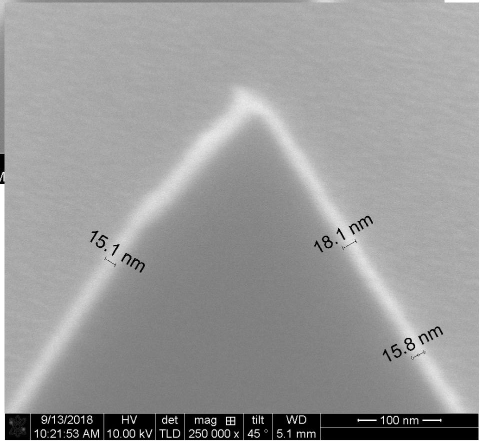
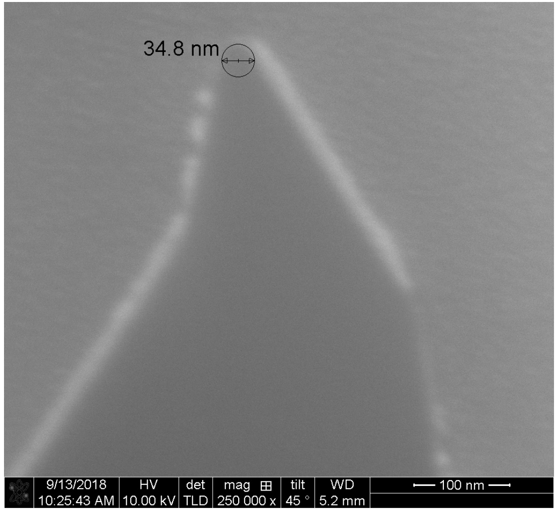


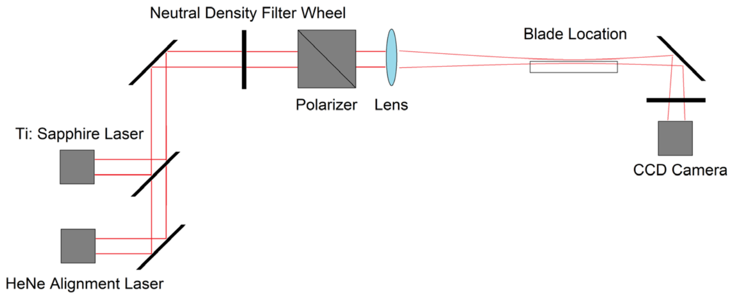
15.1 nm
18.1 nm
15.8 nm
9/13/2018 10:21:53 AM
HV 10.00 kV
det TLD
mag ⊞ 250 000 x
tilt 45 °
WD 5.1 mm
100 nm



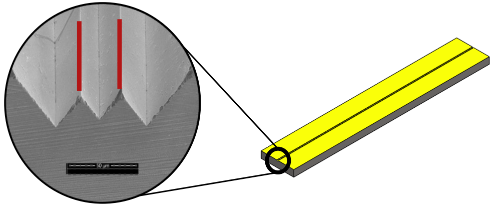
34.8 nm
9/13/2018 10:25:43 AM
HV 10.00 kV
det TLD
mag ⊞ 250 000 x
tilt 45 °
WD 5.2 mm
100 nm

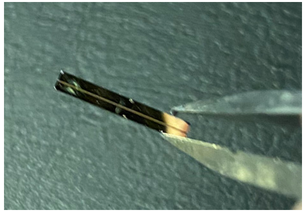
Experimental Setup

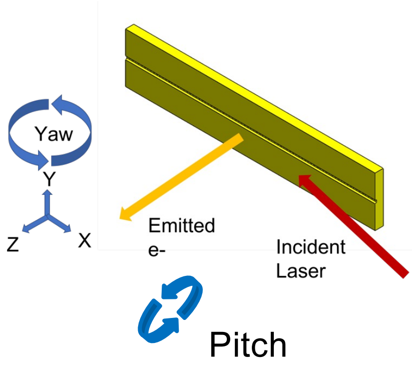
- Cathode sample 15mm x 3 mm
- 800 nm, 35 fs pulses, between 10^12 and 10^13 W/cm^2 peak, 100 um spot size, polarized normal to blade surface
- Downstream camera for alignment
- Small angle of incidence for full 15 mm blade illumination

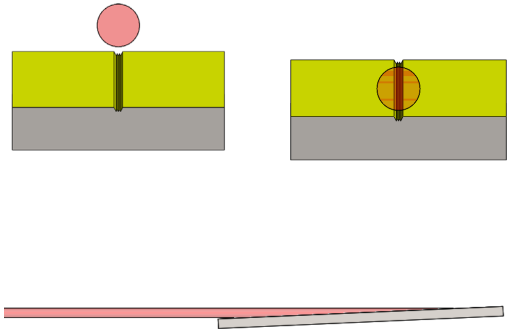


G Lawler. et al. *Instruments* **2019**, *3*, 57.



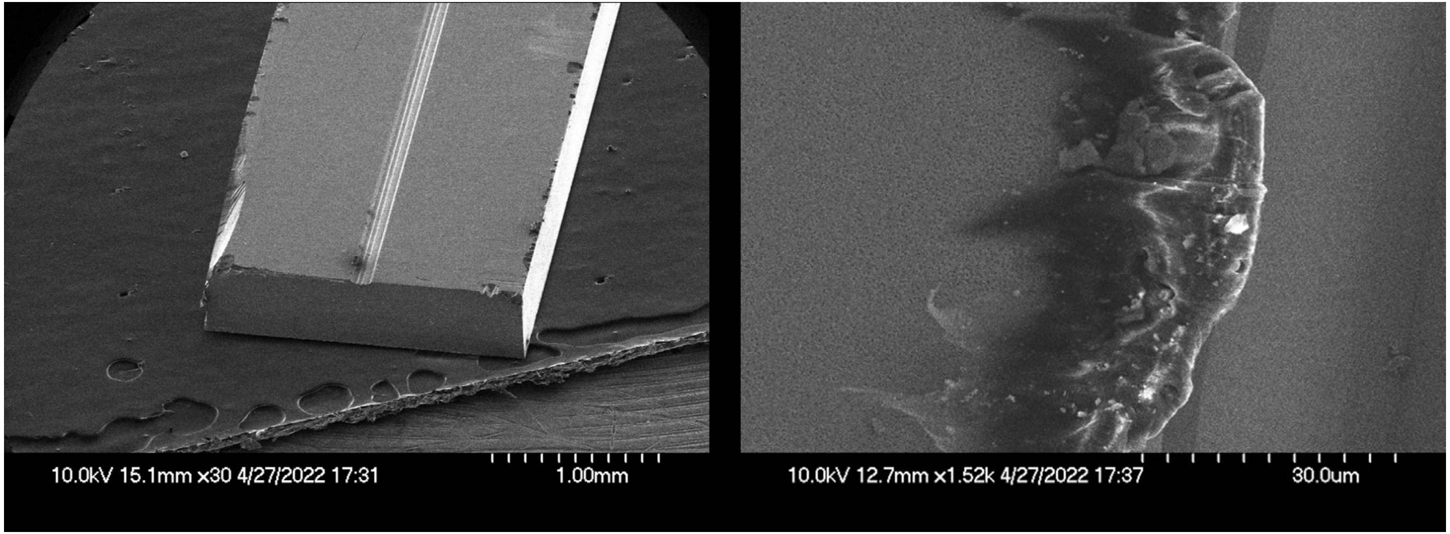






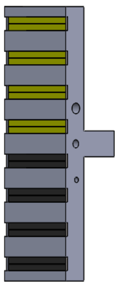
Damage Threshold

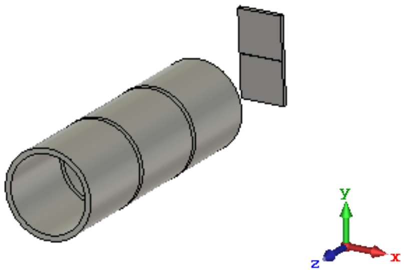
- Notable damage directly attributable to laser illumination not common below 10^13 W/cm^2 peak
- Only upon inspection and does not effect long term yield of 10^5 e- per pulse
- Possibly due more to uneven sputtering coating exposing silicon

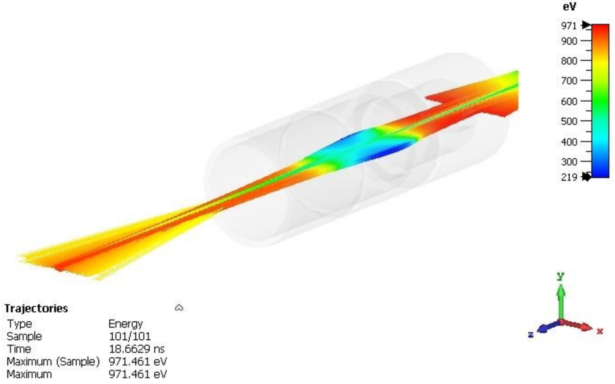


Experimental Setup (cont.)

- Sample location = biased mount containing 8 fixture locations
  - Currently 4 Au and 4 W (each with double blade geometry)
- After emission electrons can be focused onto MCP and phosphor screen 25cm away via an electrostatic einzel lens
- Advantages such as preserving energy and ease of operation
- Focus of thin line of charge difficult to spatially resolve

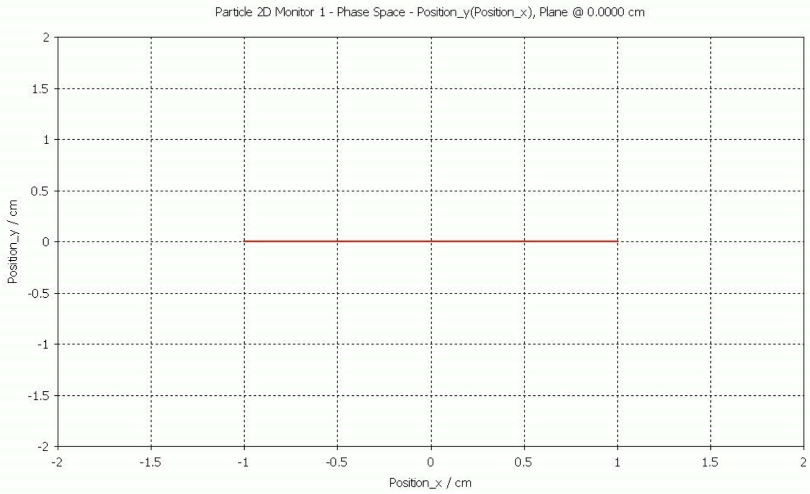


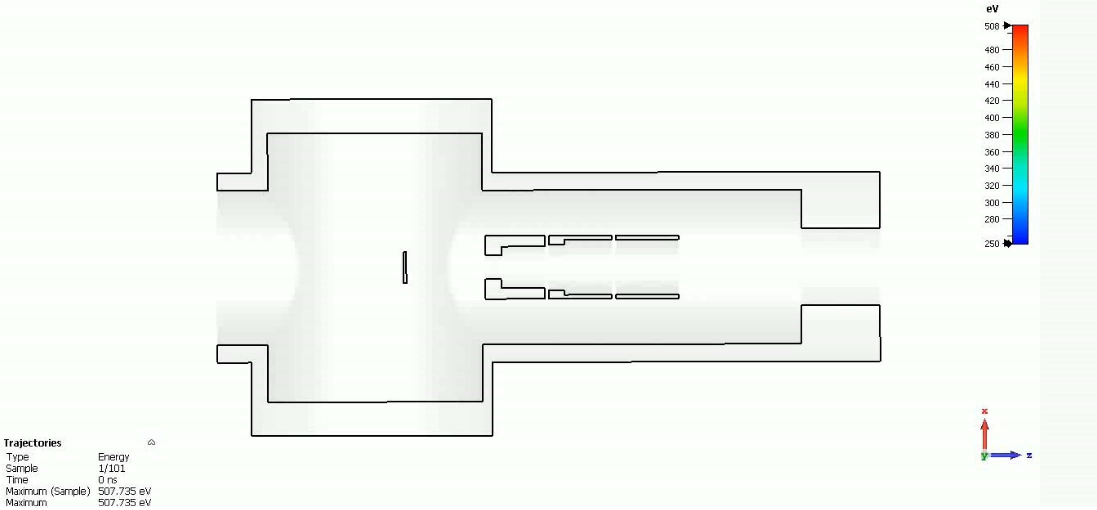




Monochromatic beam, 0eV MTE

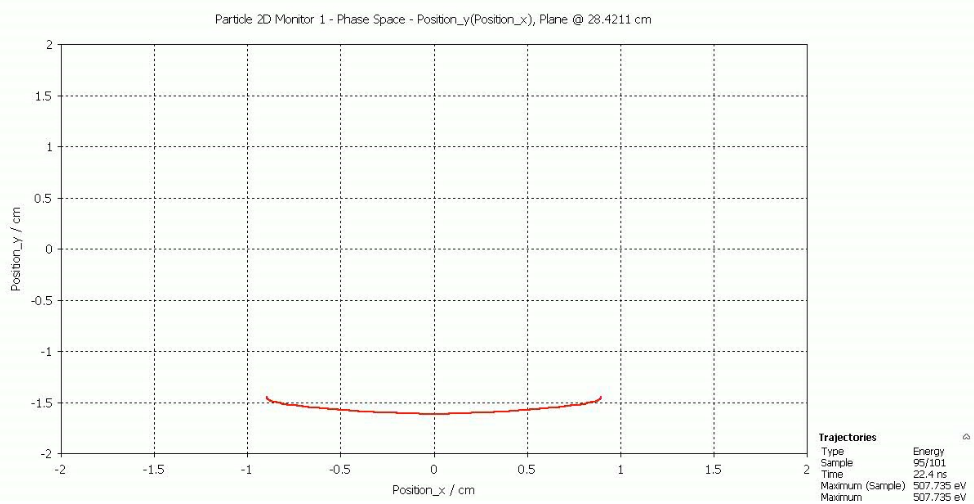
- Intentional pitch angle
- Simplified simulation of a monochromatic high aspect ratio beam with 0eV mean transverse energy (MTE)
- Transverse cross section (left)
- Trajectories of corresponding electrons (right)

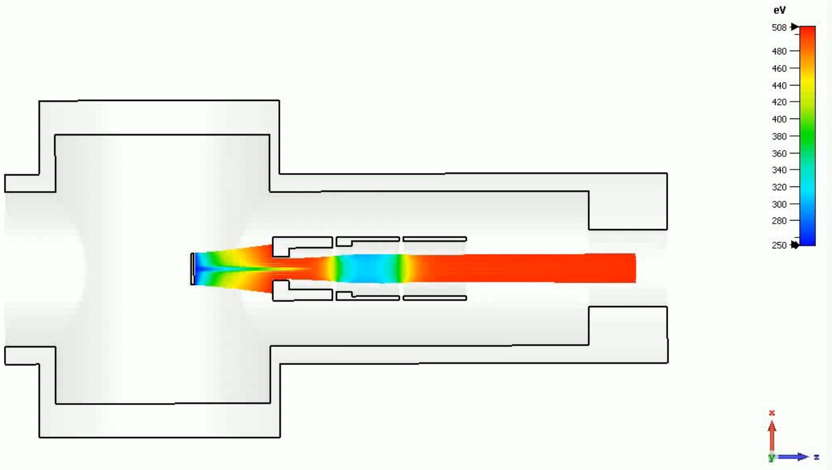




Increase Lens Strength

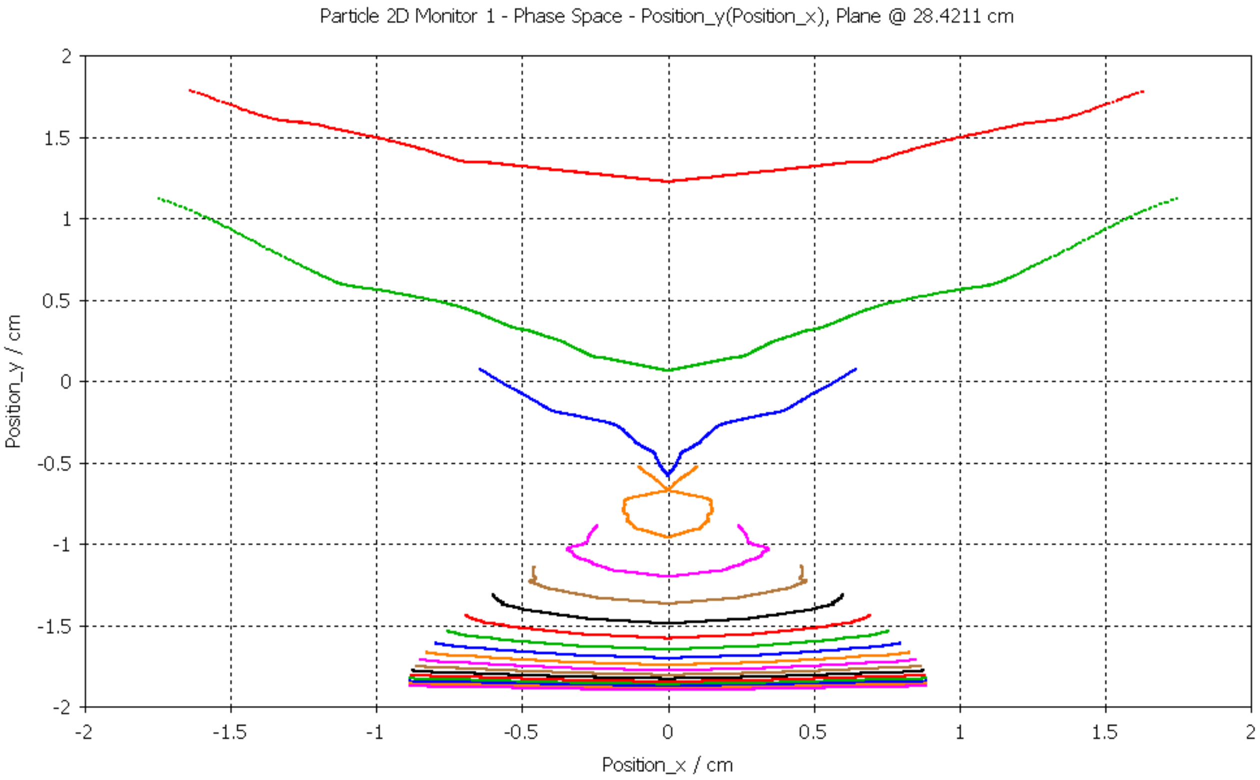
- Z coordinate of transverse cross section constant @ detector
- Increase the lens strength
- Curves beam more looping around into waist like feature before returning to line like shape





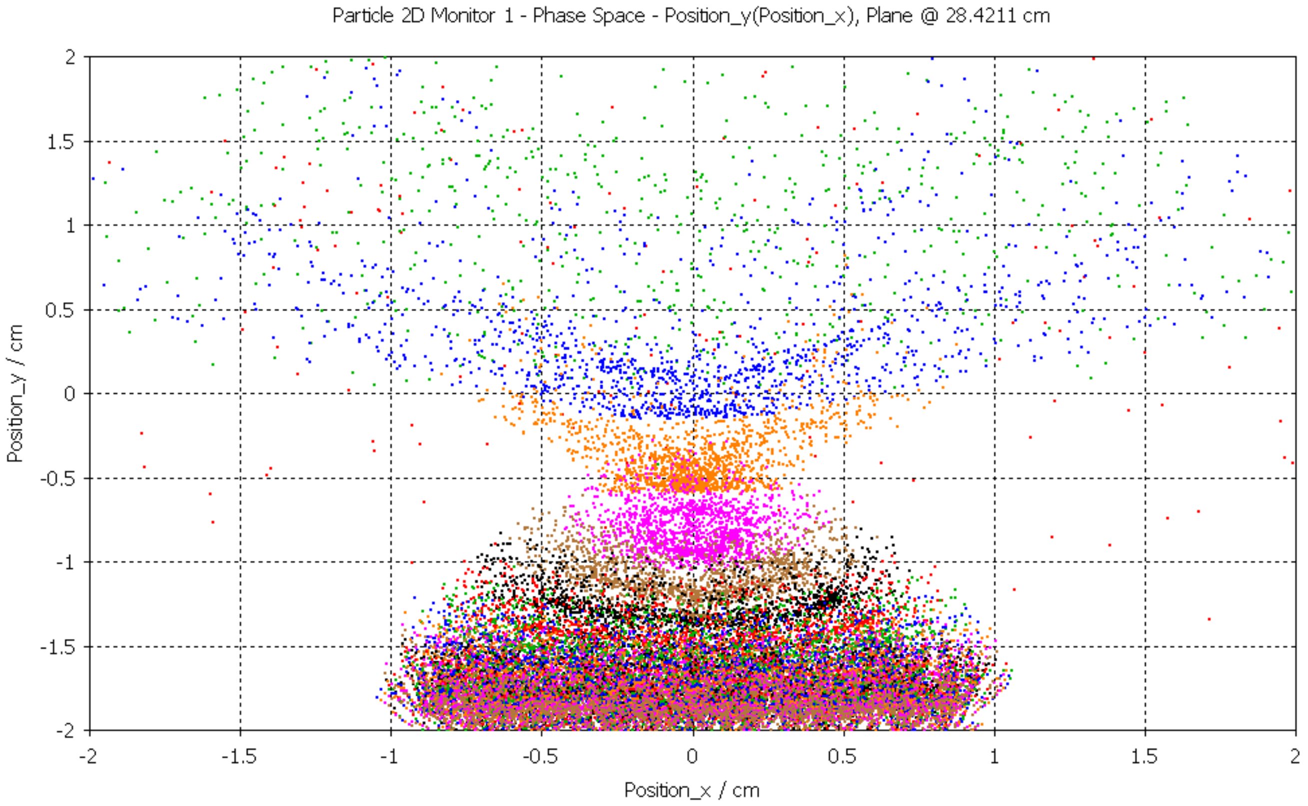
Nonzero Energy Spread

- Bins of energy at emission from 0 to 500 keV
- Voltage on lens to get focus at 25cm
- With 0 eV MTE
- Implicit energy filtering for energies below focusing voltage so bias of cathode holder necessary



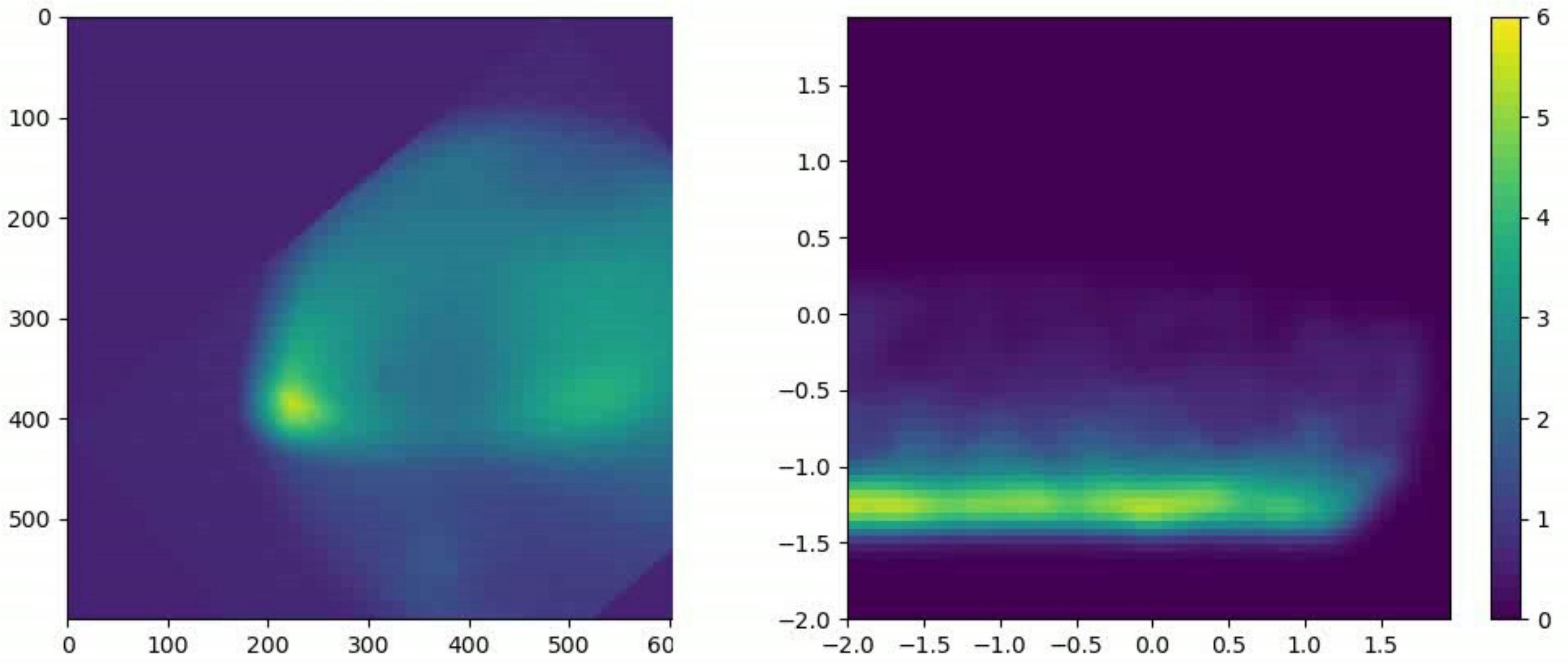
Nonzero Energy Spread 5eV MTE

- Same simulation now with 5eV MTE added due to apex curvature
- Note blurring effects
- For higher MTE distinct structure not visible
- Implying upper bound on MTE



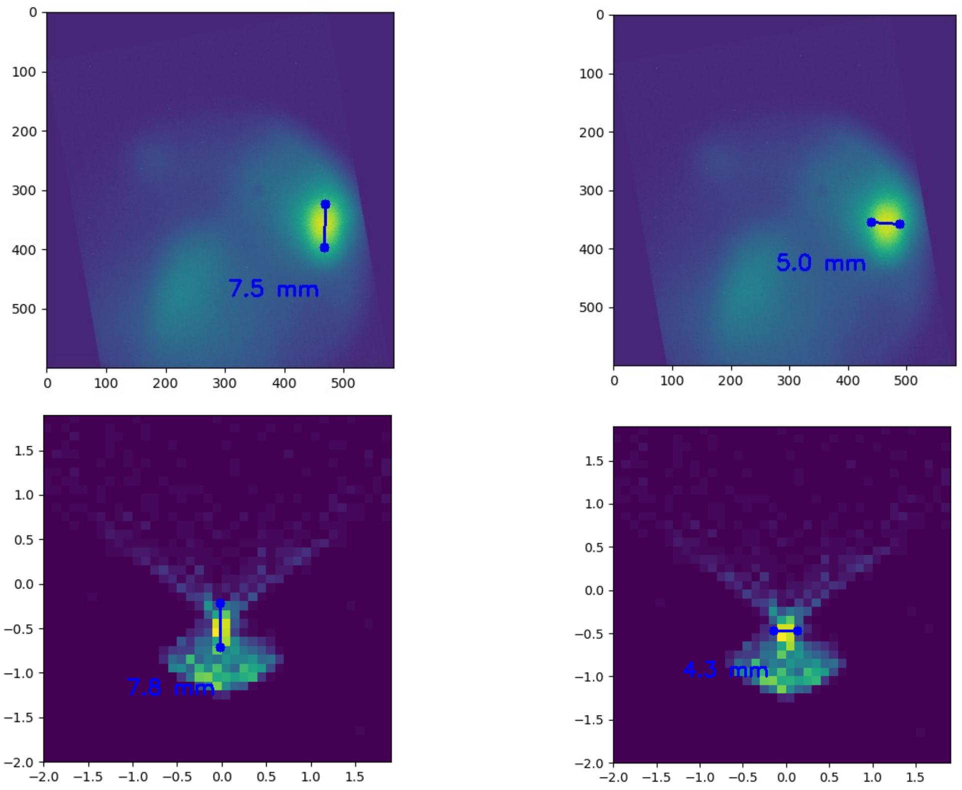
Data v. Simu

- Lens scan data data v. 500eV uniform distribution simulation with 5 eV MTE



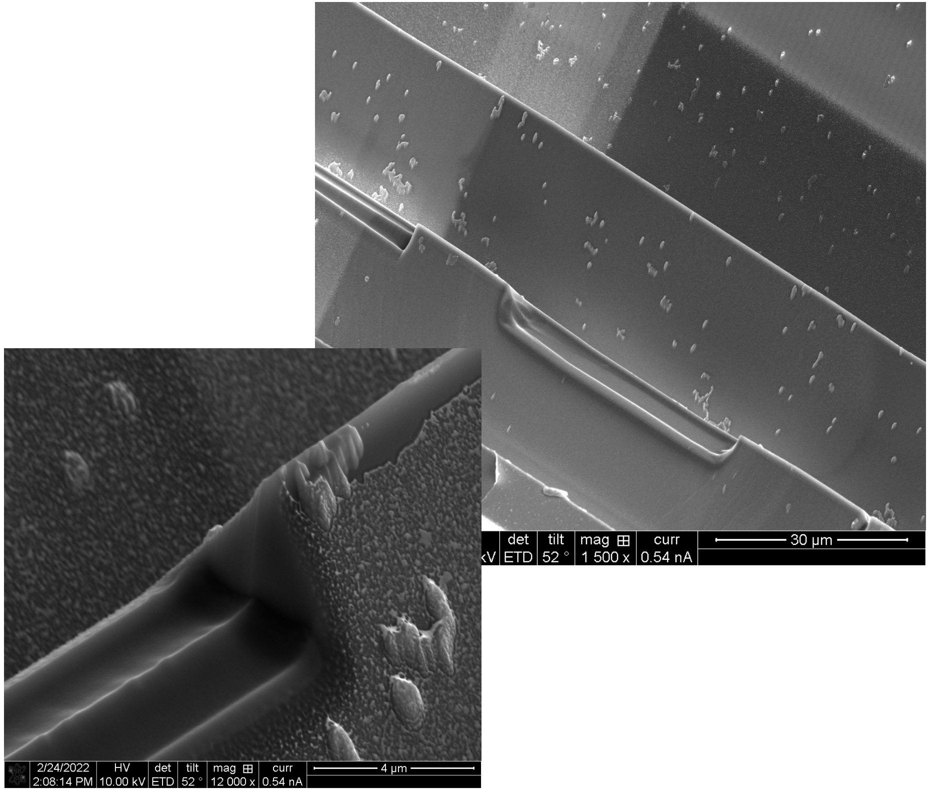
Beam "Waists"

- Beam waists @ -500V bias and -530V lens voltage
- Simulated 5 eV MTE & uniform distr. 0-1keV
- ϵ_y=136 ± 16 um rad; ϵ_x=13.7 ± 2.7 um rad wiithin 3mm radius
- Additional data for 200, 300, 400, and 800 V bias



Additional FIB Blade Sculpting

- Presence of second blade limiting emittance measurement capability
- Consider reshaping existing cathodes with focused ion beam (FIB)
- Time consuming, 30 minutes to right
- Maybe useful for future plasmonic studies and small linear beamlets



Conclusions

- Beam produced from nanofabricated cathode higher current and robustness than nanotip and measured emittance
- Pattern of nanostructure reflected in beam via high aspect ratio
- Lowering of emittance possible with fabrication modifications or additional steps

Thank You