

# Transverse properties of the electron beam emitted from a diamond nanotip

Sneha Banerjee <sup>1,2a\*</sup>, Andrei Piryatinski <sup>1</sup>, Tom Kwan <sup>1</sup>, Peng Zhang <sup>2</sup>, Chengkun Huang <sup>1b</sup>

Collaborators: R. C. Baker<sup>1</sup>, D. Kim <sup>1</sup>, R. L. Fleming <sup>1</sup>, V. Pavlenko<sup>1</sup>, H. L. Andrews<sup>1</sup>, E. I. Simakov<sup>1</sup>

<sup>1</sup>T-CNLS, T-5, Los Alamos National Laboratory, Los Alamos, NM 87545

<sup>2</sup>Department of Electrical and Computer Engineering, Michigan State University, East Lansing, Michigan 48824

\***Present Address:** Electrical Models and Simulation, Sandia National Labs, Albuquerque, NM 87111

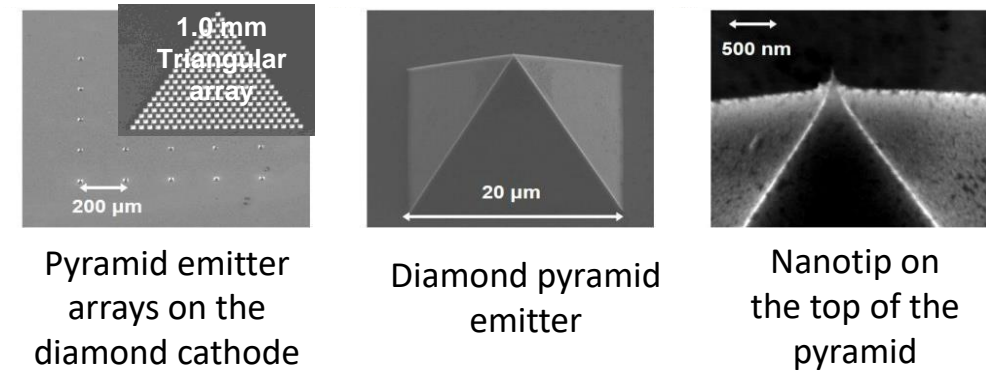
a) snebane@sandia.gov , b) huangck@lanl.gov

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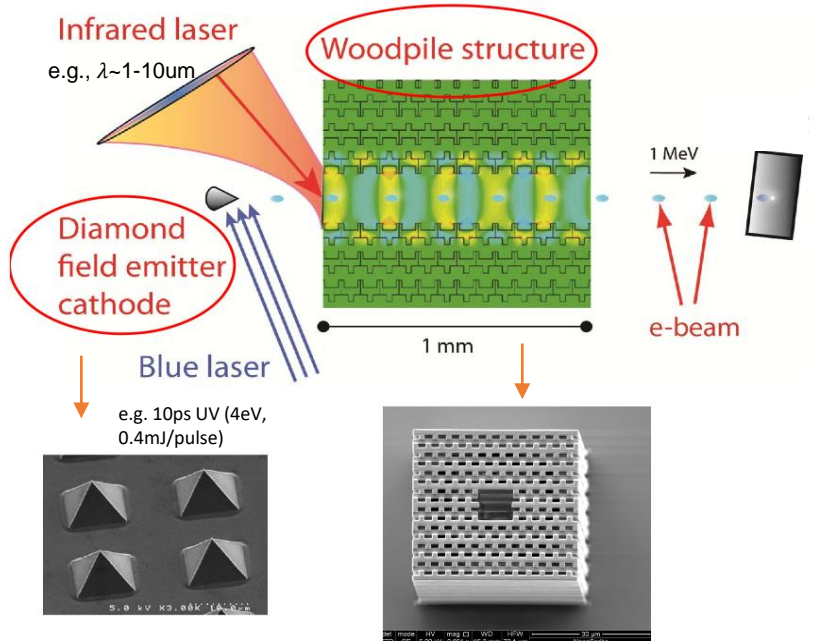
# Motivation

- Advanced accelerators provide higher acceleration gradients but require compact electron sources. **Diamond field emitter array (DFEA)** cathode is an enabling technology for **Dielectric Laser Accelerator (DLA)**.
- DFEA has  $\mu\text{m}$  size pyramids and nm size nanotips.
  - High current emission ( $> 15\sim 20 \mu\text{A}/\text{tip}$ )
  - Emission from the nano-scale tips depends on quantum effects

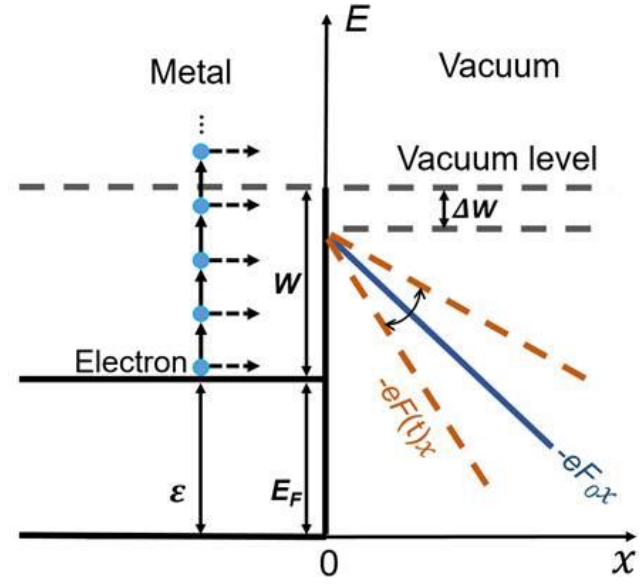
## Diamond Field Emitter Array (DFEA) Cathodes



## Dielectric Laser Accelerator

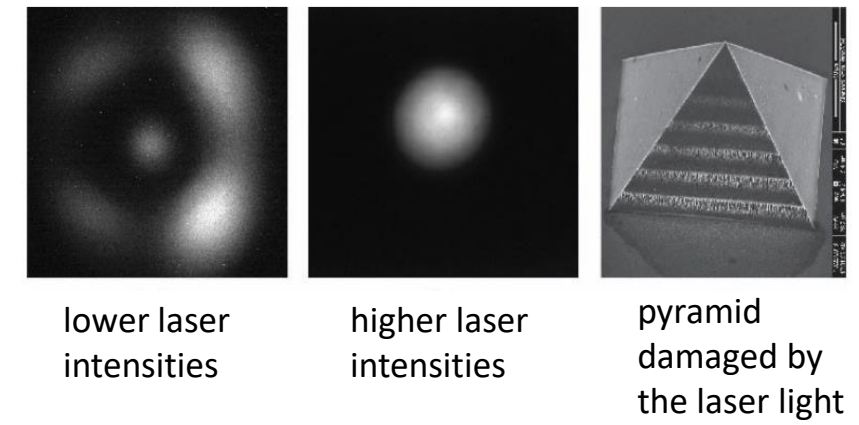


## Photoemission



Y. Luo, et al, Phys. Rev. B 103, 085410 (2021)

## Observed Emission Pattern in Experiment

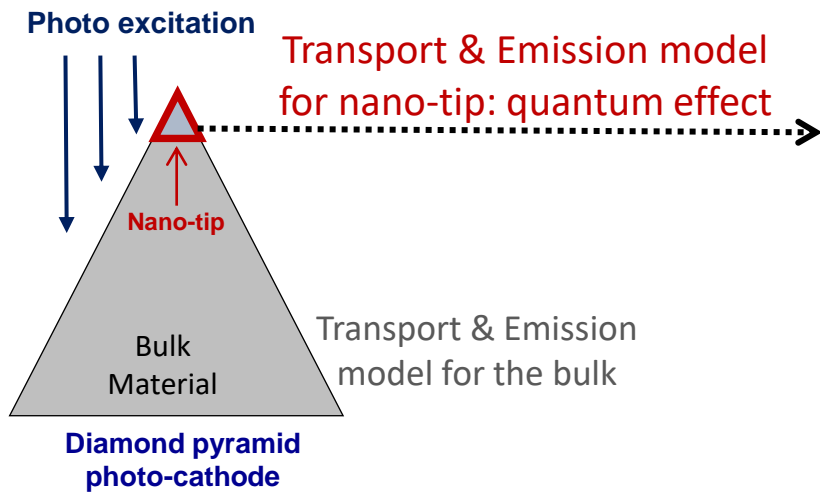


Simakov et al, 10th Int. Particle Accelerator Conf. (2019)

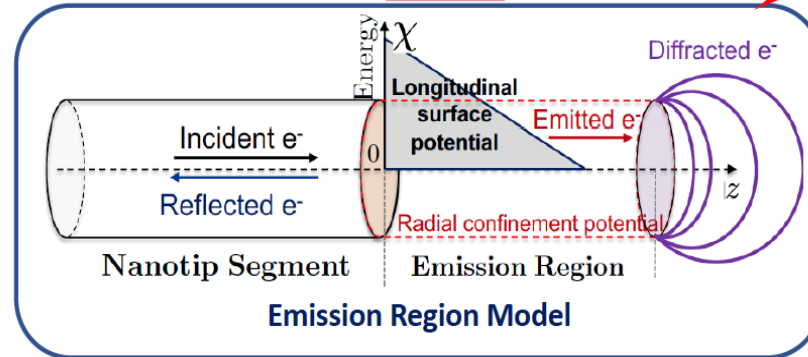
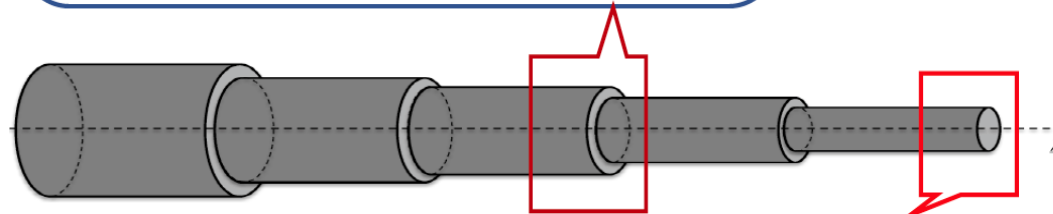
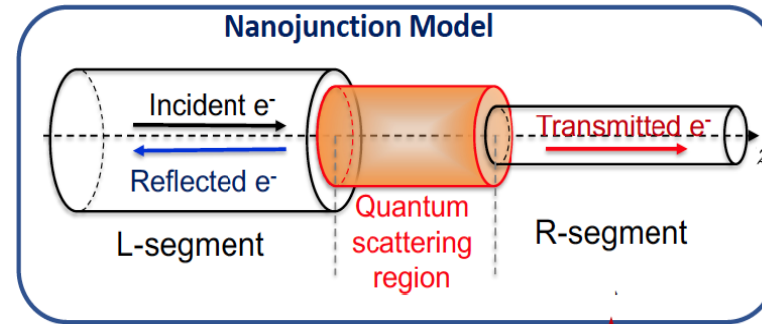
# Modeling Emission from DFEA

## Modeling diamond pyramid under photo excitation

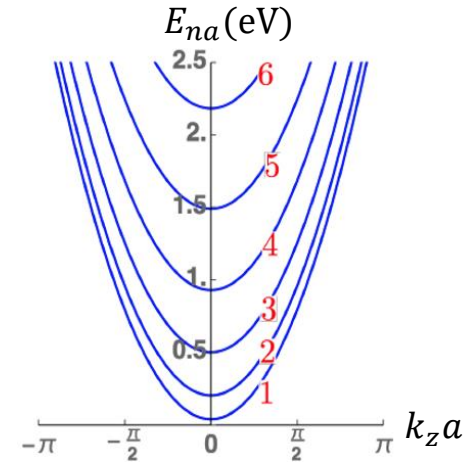
Piryatinski et al., J. Appl. Phys. 125, 214301 (2019)  
 Huang et al., J. Appl. Phys. 125, 164501 (2019)



## Modeling nanotip as a sequence of co-axial cylindrical nanowire segments



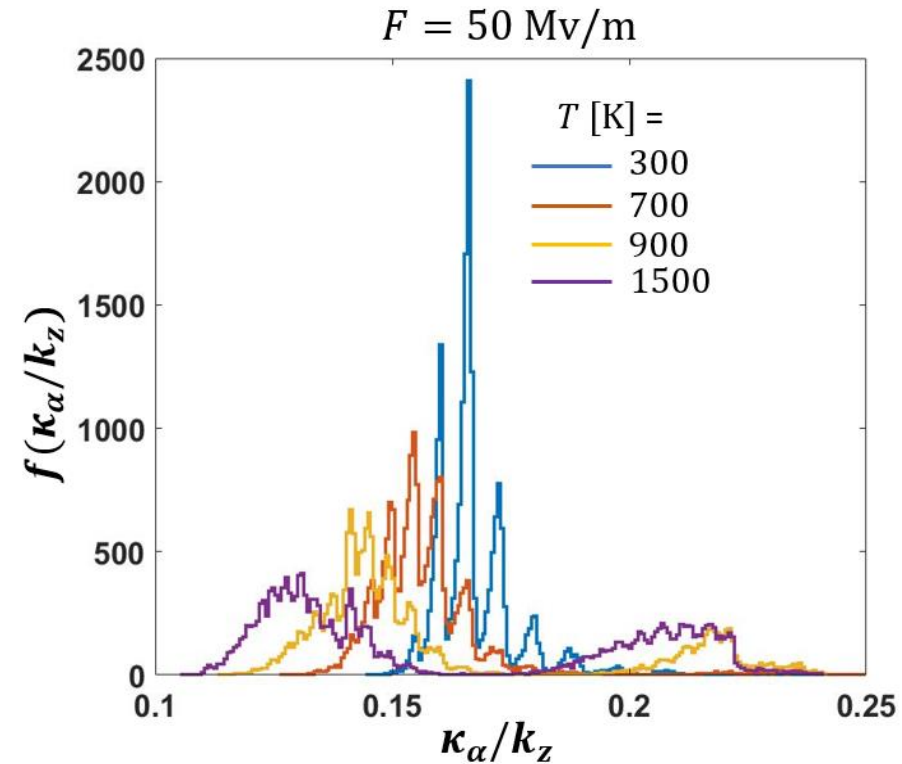
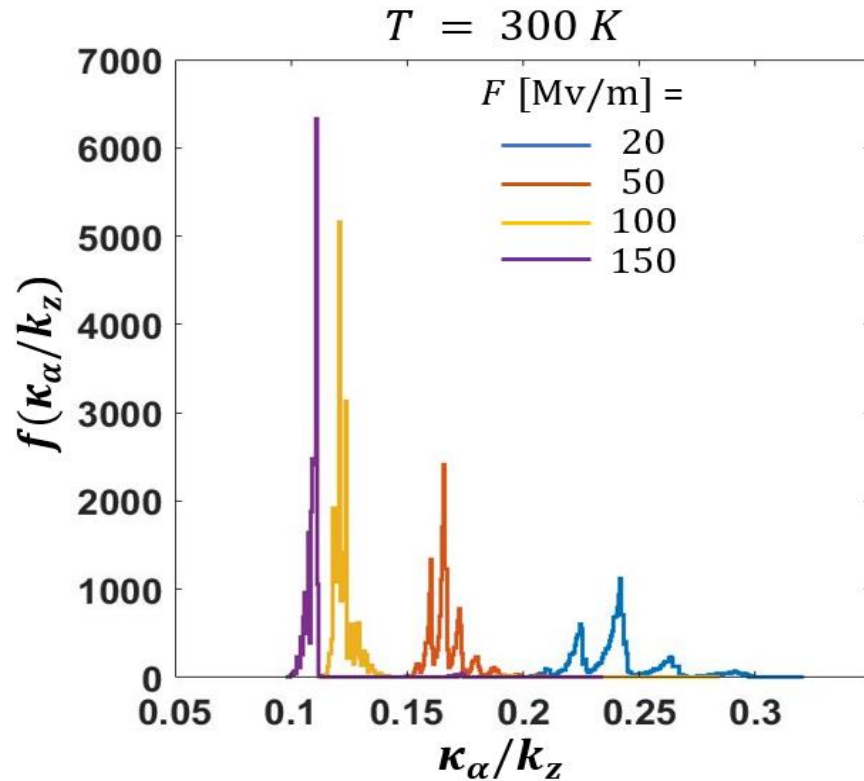
## Conduction band quantization



- quantum numbers in the radial direction  $\alpha = \{n, a\}$  denote the subbands
- $k_z$  = longitudinal momentum
- $\kappa_\alpha$  = radial momentum
- Divergence ratio =  $\frac{\kappa_\alpha}{k_z}$  is investigated.
- **Goal:** To study the transverse beam properties, to achieve better coherence.

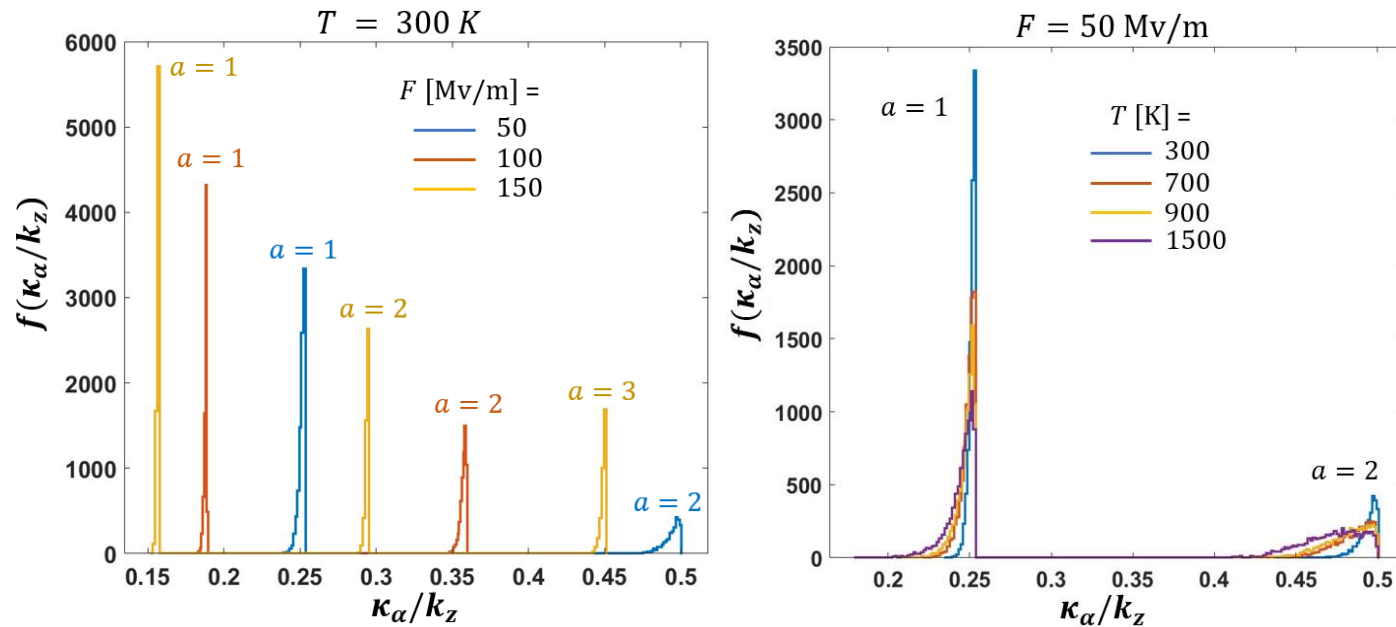
Monte Carlo Transport + Scattering + Tunneling model with band quantization

# Divergence Ratio – with Phonon Scattering



- $\frac{\kappa_\alpha}{k_z}$  decreases when external field  $F$  increases. The spread of the histograms also decreases. High brightness coherent beam.
- $\frac{\kappa_\alpha}{k_z}$  decreases when temperature  $T$  increases. However, the spread increases because more electrons move to higher quantum state  $n$ .

# Divergence Ratio – without Phonon Scattering



- Little energy loss without phonon scattering, electrons move to higher subbands (higher  $a$ ) when the applied field  $F$  is increased.
- Since the initial electron distribution (Maxwellian) depends on temperature, the spread of  $f(\kappa_\alpha/k_z)$  varies a little with temperature too.

## Summary

- Monte Carlo + tunneling model including the quantum effects at the nanotip gives new emission characteristics → enables high brightness compact electron sources.
- Divergence of the emitted beam depends on **applied field, temperature, and initial quantum states**.
- In future, this work can be extended to include **bulk transport** and **arbitrary number of nanowire segments**.

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