Application of FEgen for Guided Development of Transversely Shaped Beams using Field Emission Arrays

Emily Jevarjian[1,2], Mitchell Schneider[1,2,3], Kimberly E. Nichols[3], Heather L. Andrew[3], Dongsung Kim[3], Jiahang Shao[4], Evgenya I. Simakov[3] and Sergey V. Baryshev[2]

1)Department of Physics and Astronomy, Michigan State University, MI 48824, USA

2)Department of Electrical and Computer Engineering, Michigan State University, MI 48824, USA

3)Accelerator Operations and Technology Division, Los Alamos National laboratory, Los Alamos, NM, 87545,USA

4)High Energy Physics Division, Argonne National Laboratory, Lemont, IL 60439, USA

Introduction

Field emitters are poised as next-generation cathodes capable of operating at high frequencies and high peak power: compact and naturally suited for shaped and patterned beam production. We developed a computational toolbox to realistically model the particle dynamics in field emitter cathode systems.

The algorithm can account for field emission technology beyond the Fowler Nordheim law

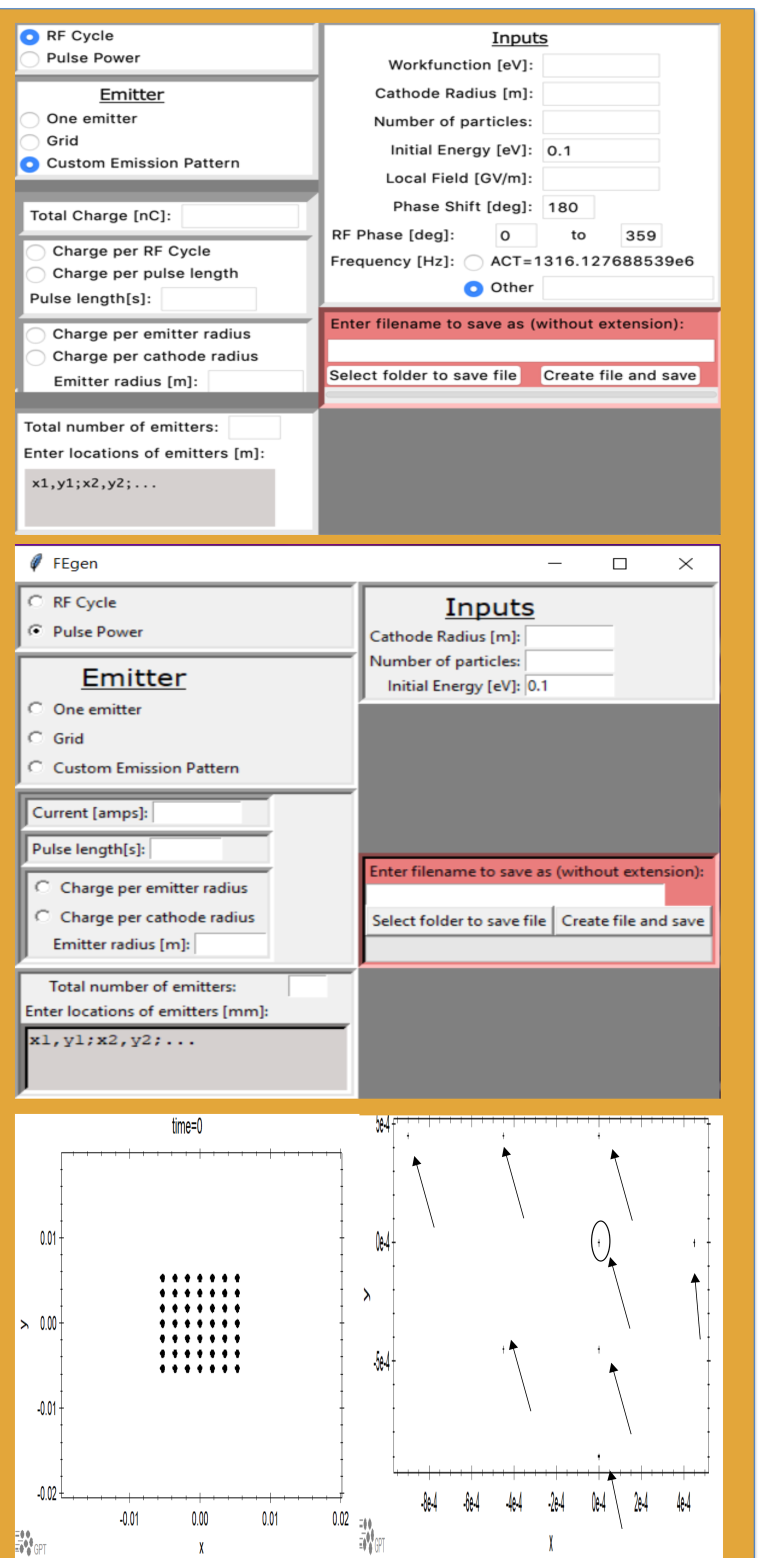
- Nonplanar geometries
- Semiconductors (Stratton-Baskin-Lvov-Fursey)
- Temperature dependent emission (Murphy-Good)
- Compatible with ASTRA, Impact-T, and GPT

FEgen Capabilities

- FEgen provides capabilities for both RF and DC/pulse power environments
  - Allows for emission patterns consisting of one emitter, emitter grid, or custom emitter pattern
  - Pulse power/DC option assumes a flat top current is used to create a time-uniform charge distribution Q=I* τ
  - RF environment uses the Fowler Nordheim equation in RF field
  - Inputs experimental data for charge collected over a pulse: $Q_{rf} = \frac{Q}{\tau * f}$
  - Simulates different cathode dimensions to optimize design: $Q_{rf} = Q\left(\frac{R_{cathode}}{R_{emitter}}\right)^2$
  - Can be used for a single RF cycle for different cathode radii and pulse lengths

- Emission period, initial energy spread, local field, and work function can be varied to simulate a wide variety of experimental settings and different emission physics
- Output files can be directly imported into ASTRA, GPT, or Impact-T for beam tracking simulations
  - Flags are set to -1 as the particles are generated at the cathode surface

FEgen is an open-source freeware software. Ongoing improvements include potential barriers for nonplanar geometries and temperature dependence.



RF Settings (top) , pulse power/DC settings (middle) , example of grid x-y pattern (bottom left), example of custom emission pattern (bottom right)

Acknowledgments

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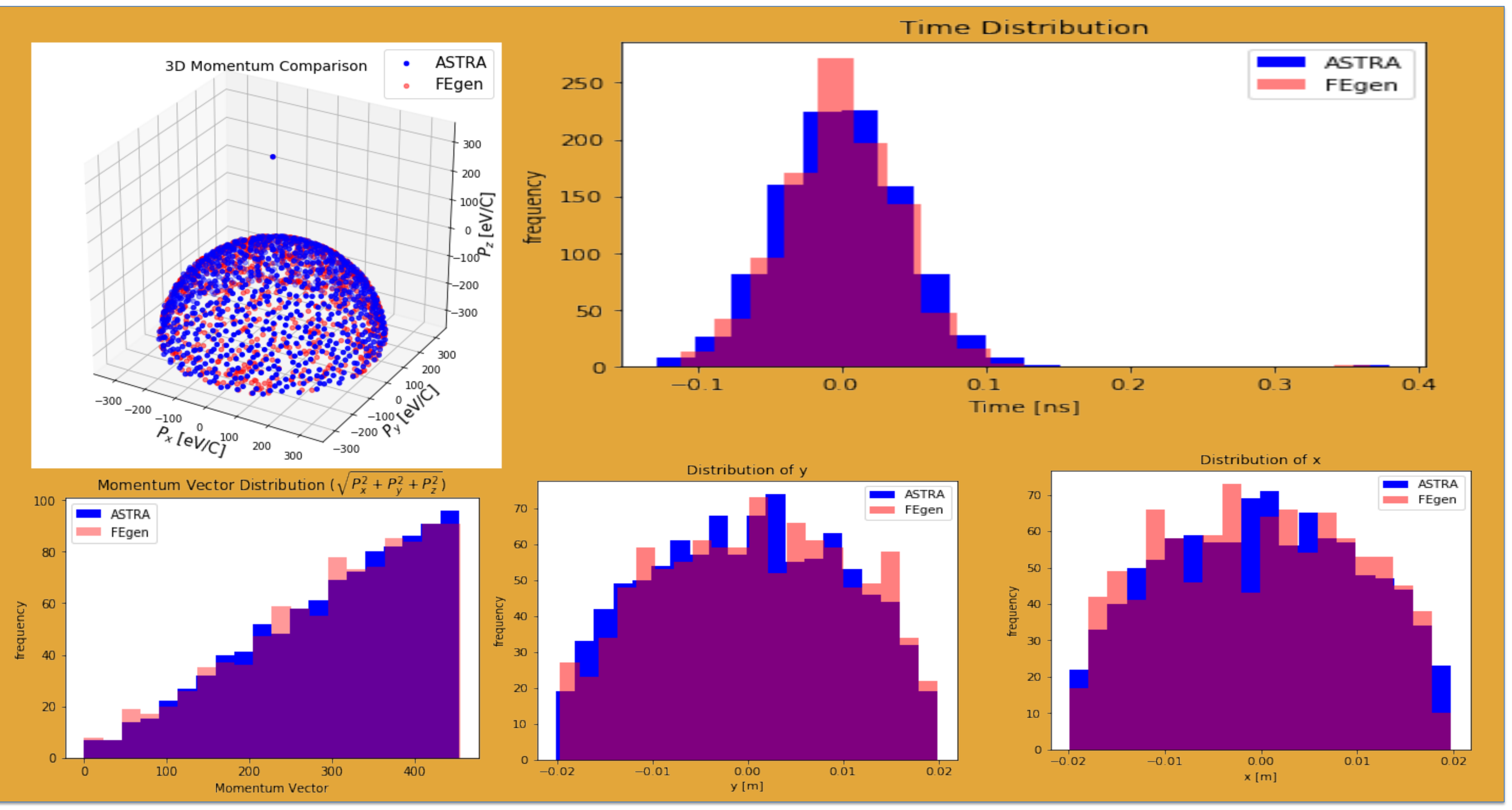
Field Emission Distribution Algorithm

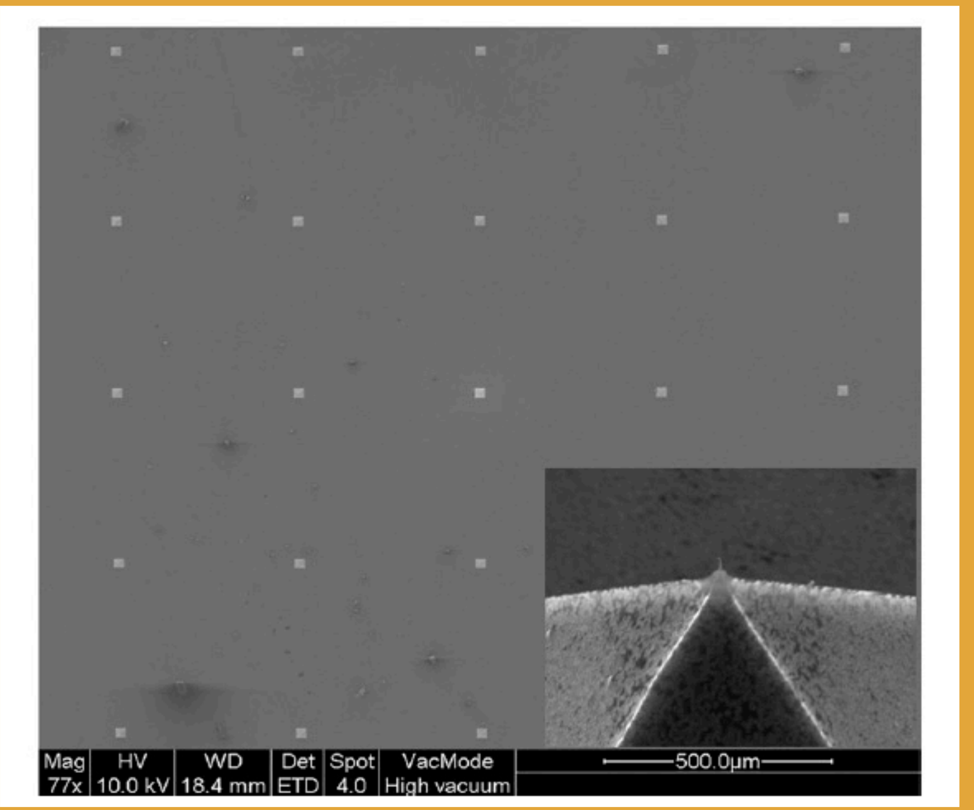
- Similar to ASTRA, FEgen can create field emission distributions
- FEgen expands upon ASTRA with capabilities of using custom patterns, grids of emitters, and pulse power/DC options
- **Momentum Distribution** in FEgen is an isotropic distribution (uniform over half sphere)
  - The particle above the sphere is a test particle with all momentum in z
  - Each particle's energy is evaluated using Scipy's Statistical Kolmogorov-Smirnov test (kstest) for significance level (alpha=0.01) to create a uniform kinetic energy distribution
- **Spatial-Temporal Distribution** in FEgen is radially uniform
  - Pulse power/DC options use a uniform temporal distribution
  - RF Fowler Nordheim equation becomes a Gaussian distribution when averaged over an RF cycle:

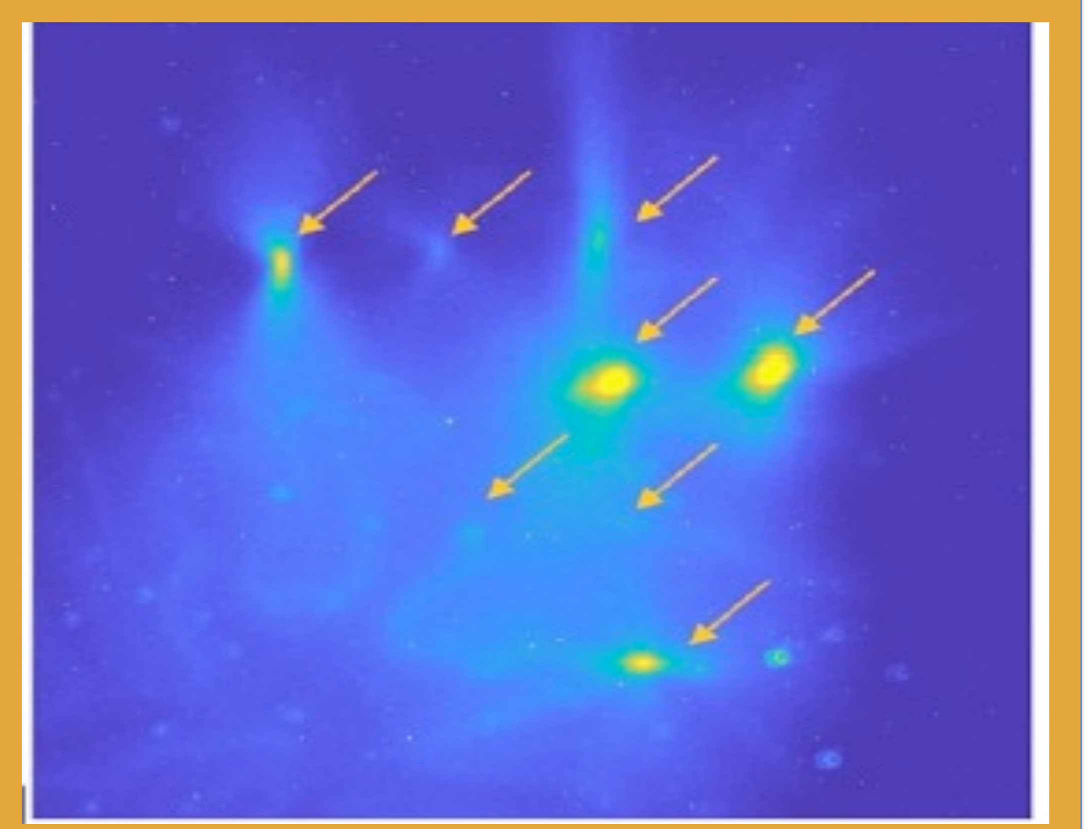
$$\bar{I} = \frac{5.7*10^{-12}*10^{4.52*\phi^{-0.5}} A_e[\beta*E_h]^{2.5}}{\phi^{1.75}} * Exp\left[\frac{-6.53*10^{9}*\phi^{1.5}}{[\beta*E_h]}\right]$$

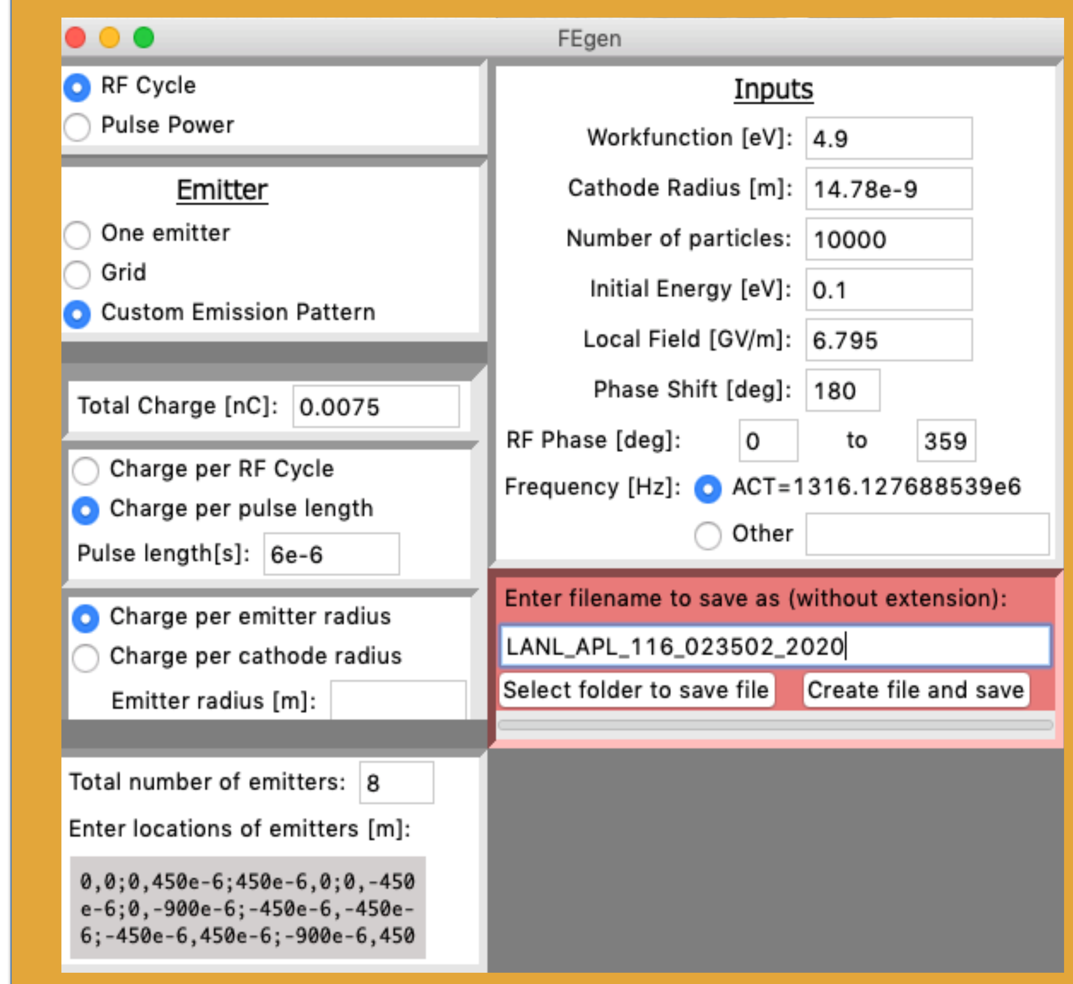


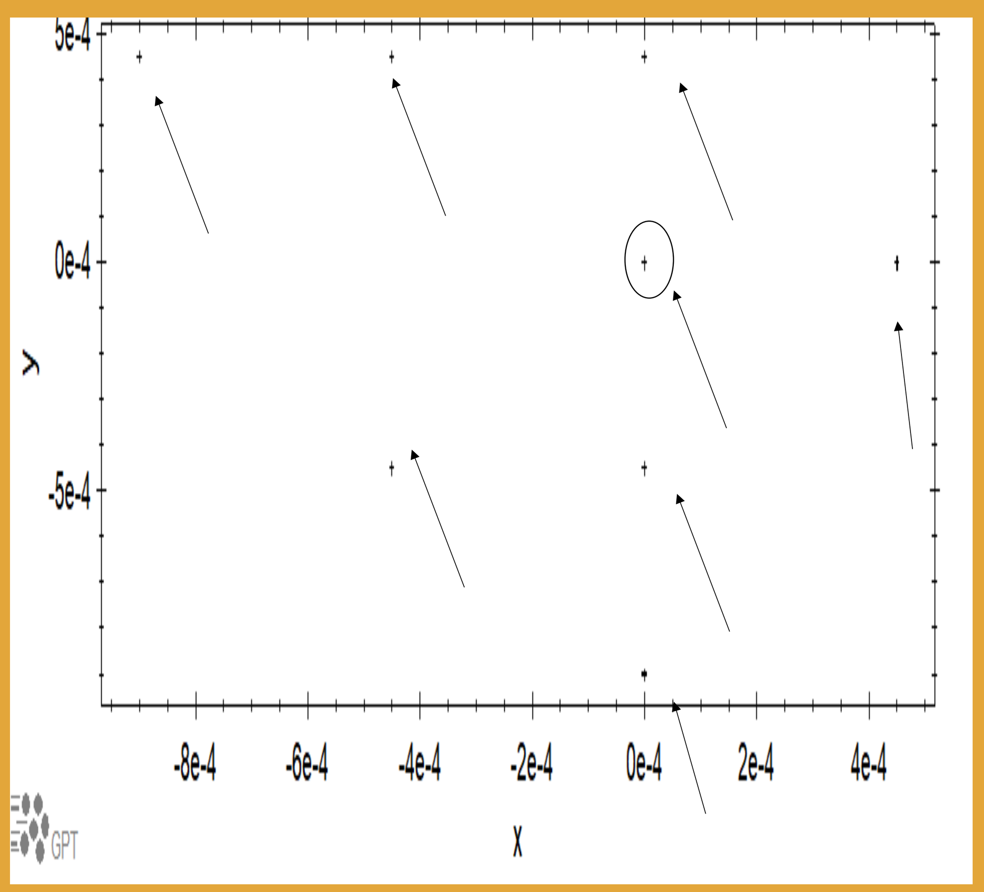
Application Example: Modeling of Patterned Beam Using Field Emitter Array

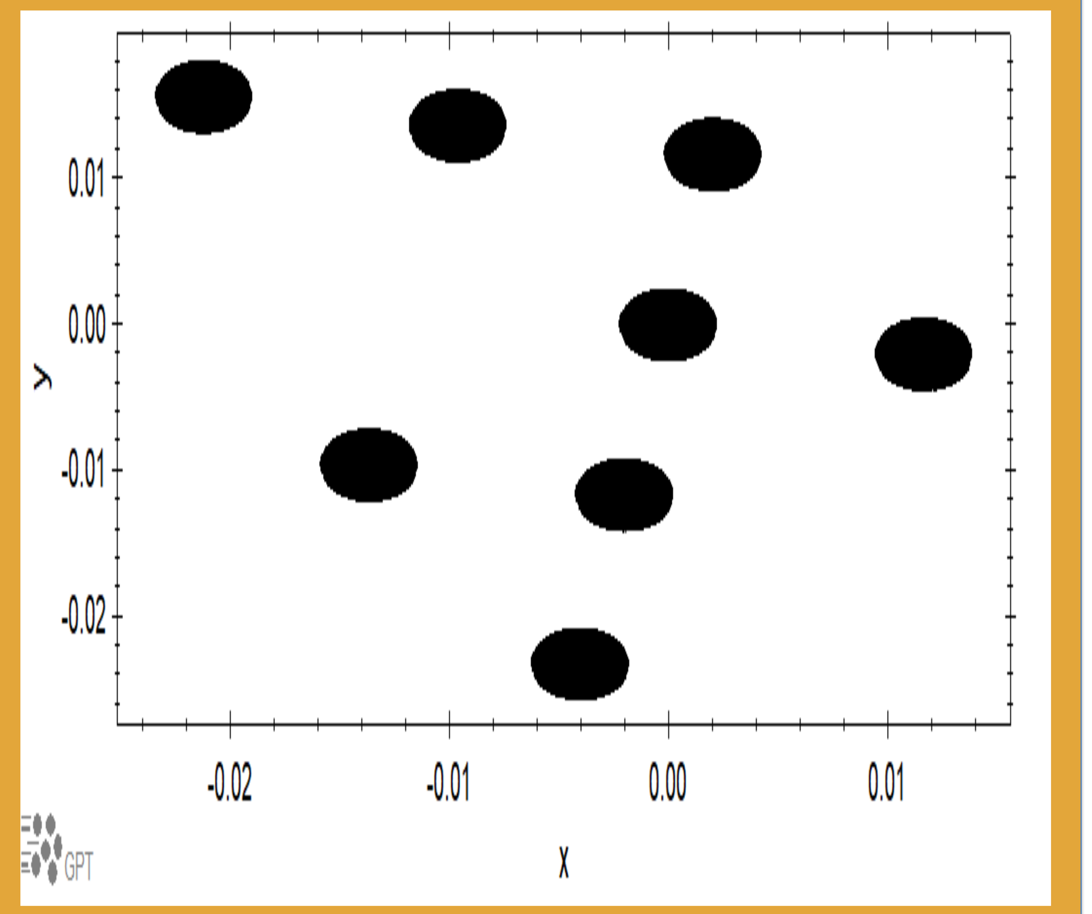
- Field emission arrays produce transversely patterned beams without complex laser schemes of masking of the cathode
  - Transversely shaped electron beam can be converted into longitudinally shaped beam by emittance exchange or a similar schematic
  - In this example, the beam is produced by an array of diamond pyramids
  - 8 diamond pyramids were emitting as shown on a YAG screen 2.54m downstream
- FEgen uses GPT and the exact solenoid settings to produce the correct gradient patterned beam at the right location with the same local field, effective emission area, work function, and charge
- FEgen coupled with GPT demonstrates time dependent simulations with extremely high resolution and accuracy not found in ASTRA or Impact-T











SEM image of cathode (top left), YAG3 image (top right), initial distribution from FEgen at z=0 in GPT (bottom left), GPT simulation results at the location of YAG3 (bottom right)