Shaped Beams from Diamond Field-Emitter Array Cathodes

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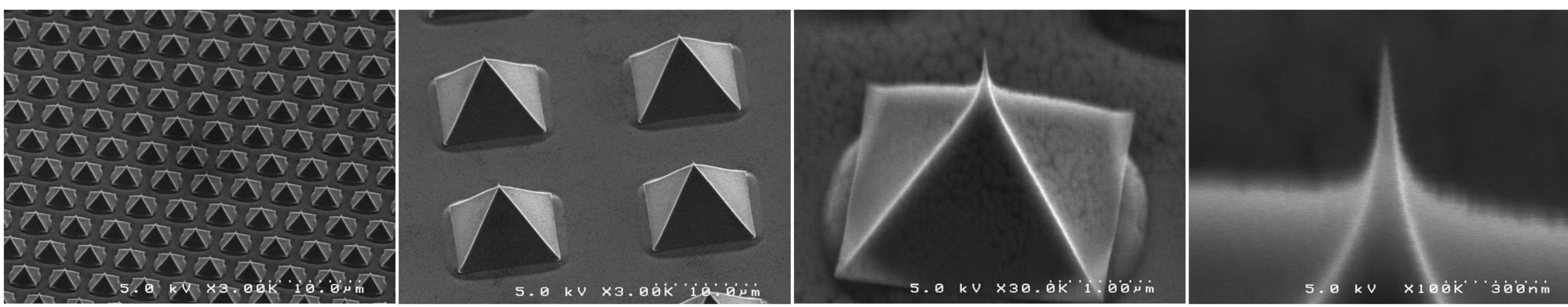
Diamond field-emitter arrays are promising cathodes

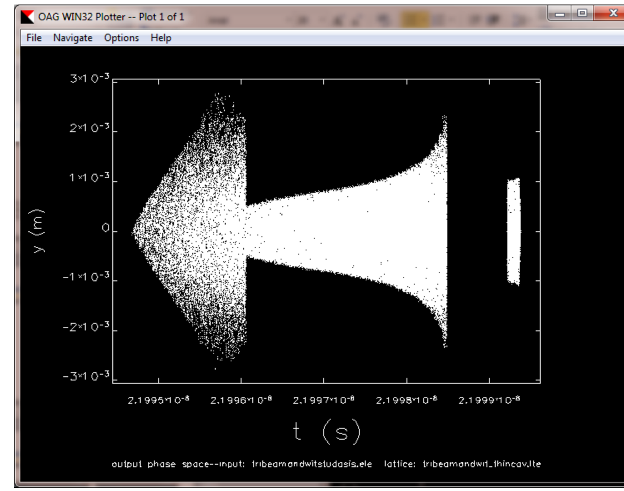
DFEAs are arrays of diamond pyramids with exquisitely sharp tips.

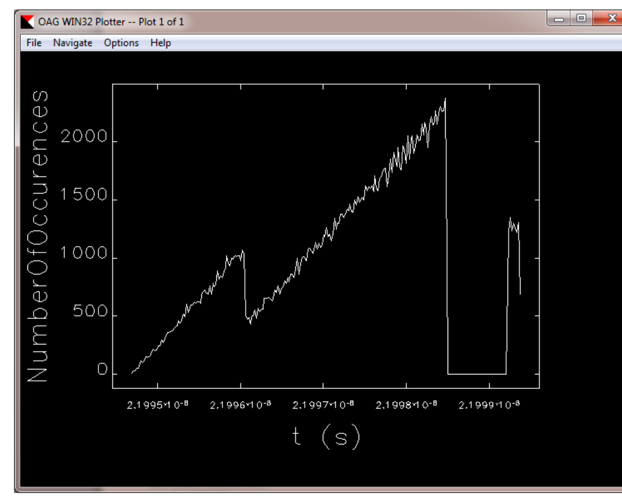
- Fabricated using standard silicon wafer technology
- Made in any array configuration
- Have demonstrated high per tip current ~ 20 μA (DC)
- Array emittance measured to be < 1 μm/mm^2 (DC)
- Photoemission, DC, and RF emission under investigation

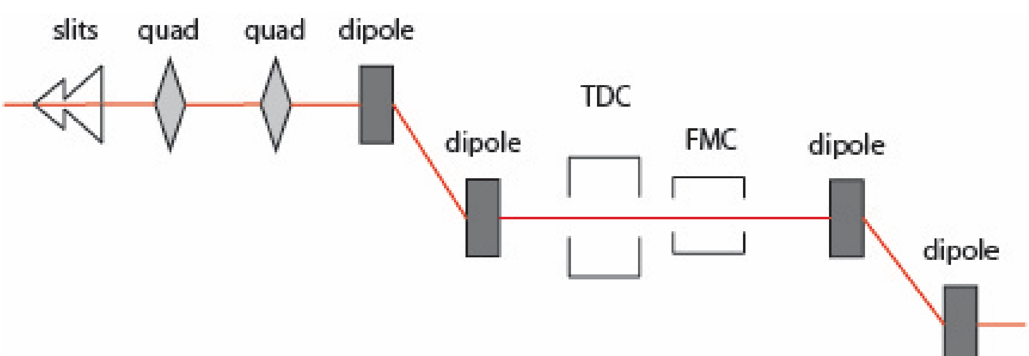


Inherently shaped beams are useful for DWA and other applications

- We are developing intrinsically shaped beams
- Transversely shaped -> EEX -> Longitudinally shaped
- High Transformer Ratio for DWA

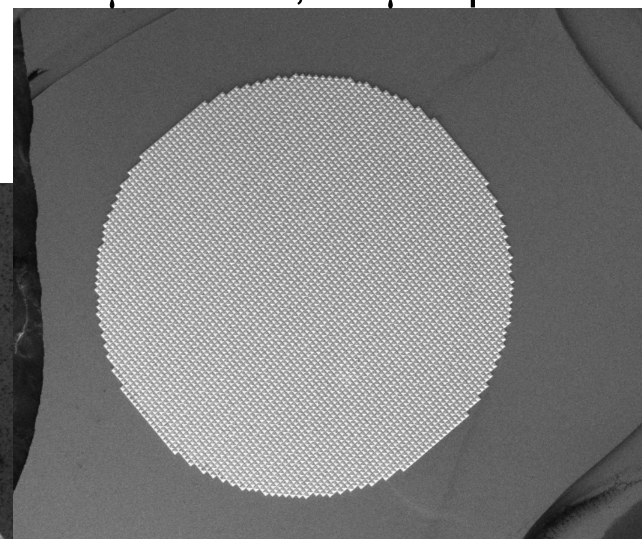




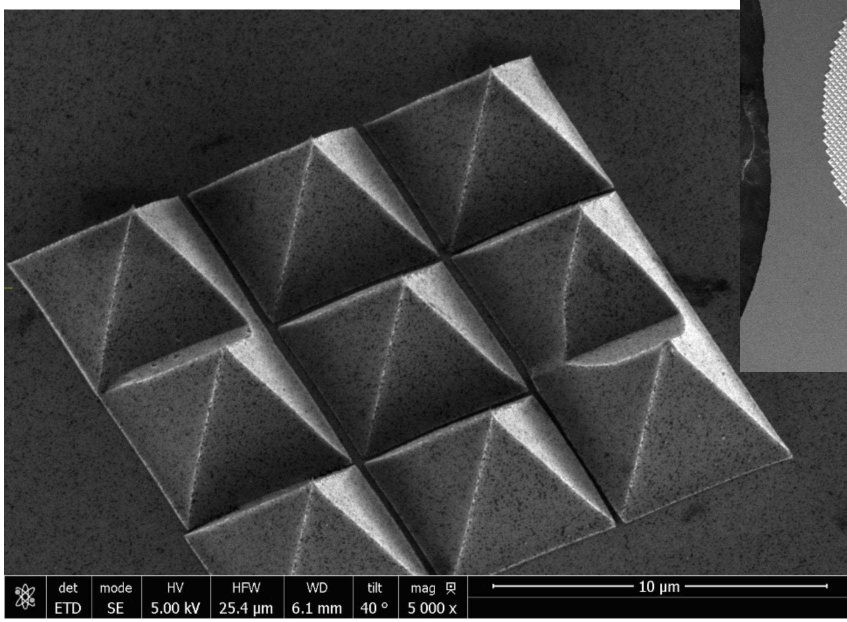


Various arrays that we have fabricated at LANL

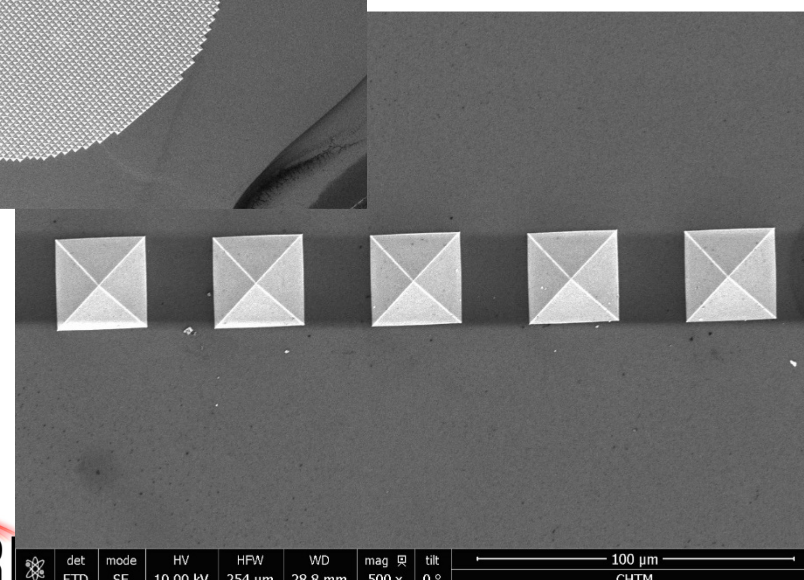
1 mm dia circle, dense
20 μm base, 23 μm pitch



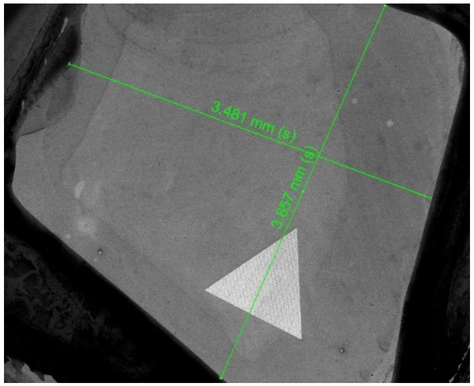
3x3 dense array
5 μm base, 5 μm pitch

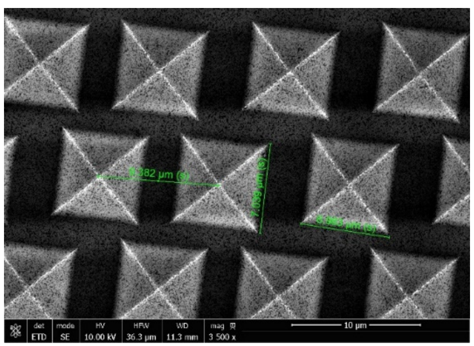


Linear array
25 μm base, 50 μm pitch

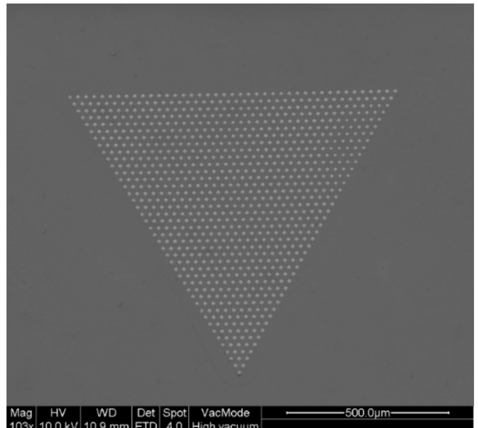


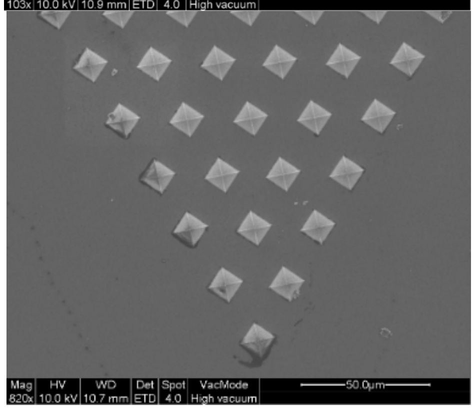
Cathodes Tested at ACT - AWA



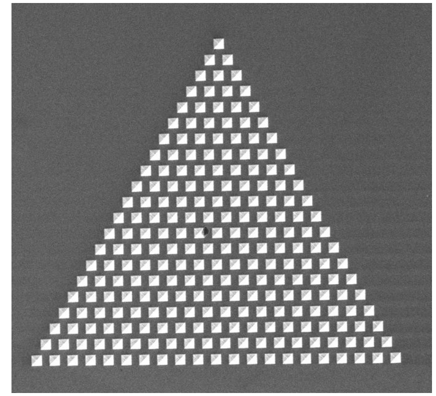


7 µm base,10 µm pitch
"CAT1"

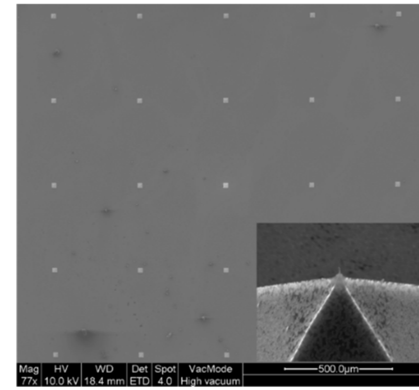




10 µm base, 25 µm pitch
"CAT2"



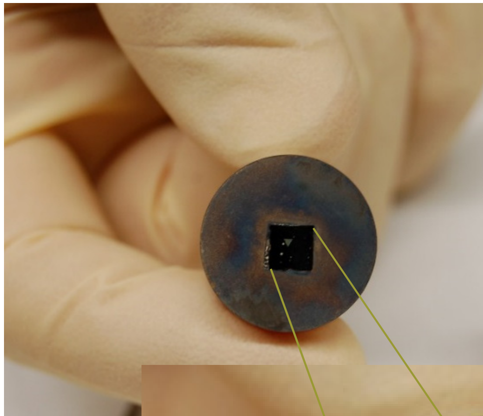
25 µm base,
50 µm pitch
"CAT3"

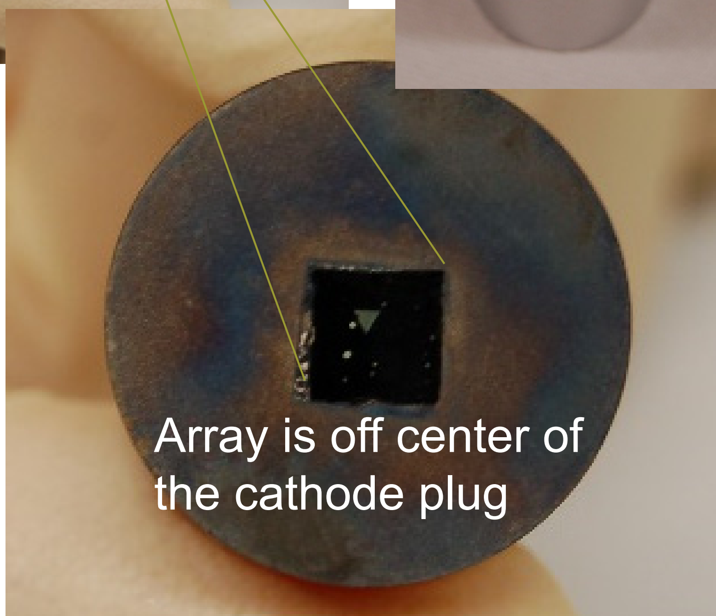


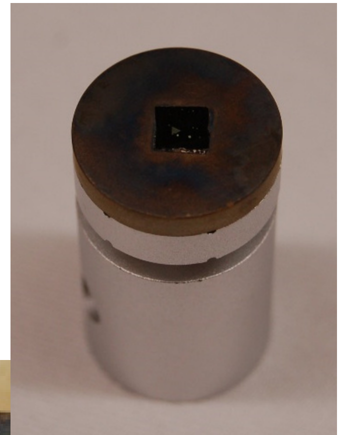
5 x 5 array
25 µm base
400 µm pitch
"SPARSE"

Triangles all
1mm per side.

Cathode plugs







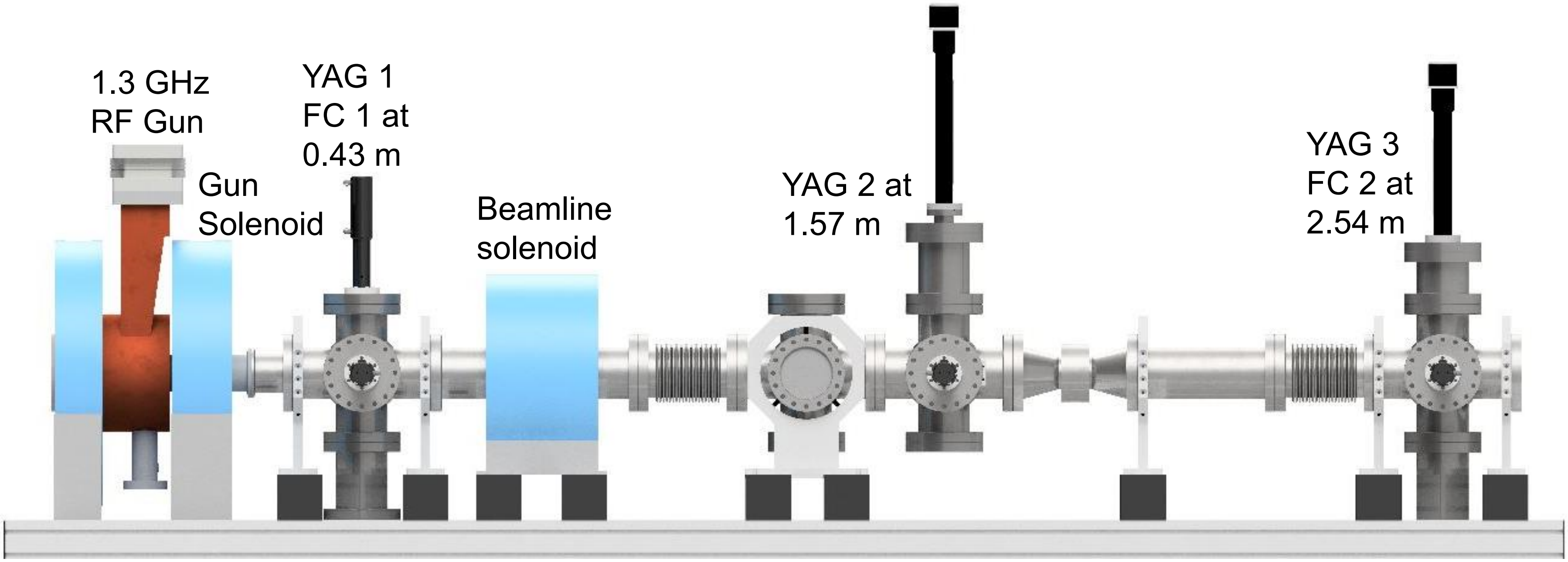
Cathode with three-part plug design

Diameter: 20 mm
Height: 35 mm

New cathode plug with rounded edge to reduce edge emission

Better array centering.

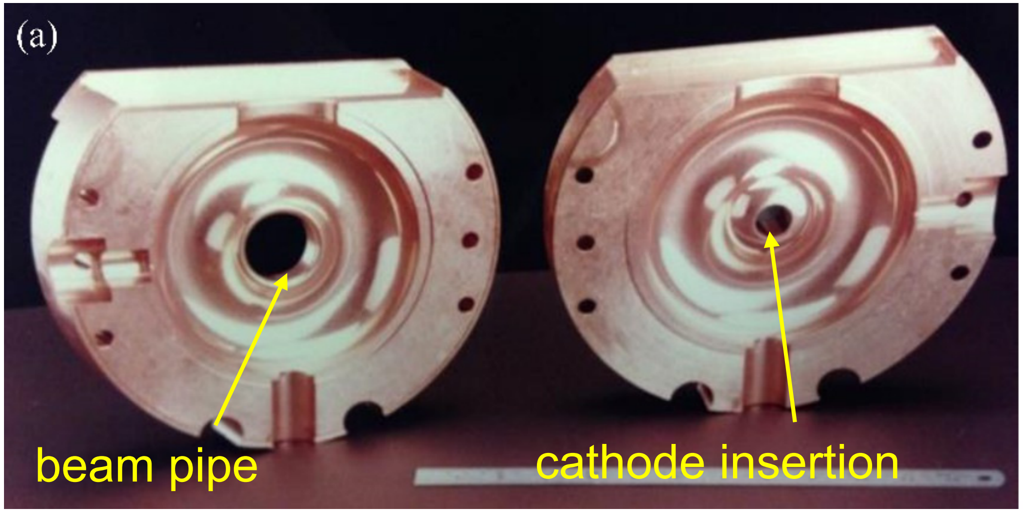
Details of ANL ACT test stand

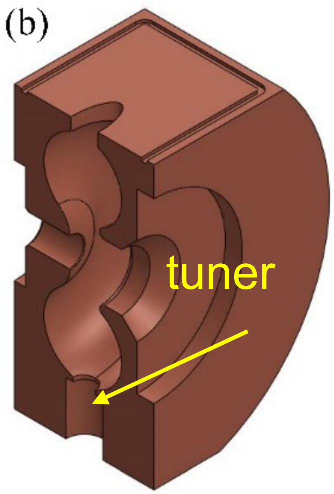


- Gun solenoid
- Beamline solenoid
- Three YAG screens,
- Two Faraday Cup diagnostics

ANL- ACT 1.3 GHz gun details

- **High gradient (100-700 MV/m) with modest rf power (2.5 MW)**

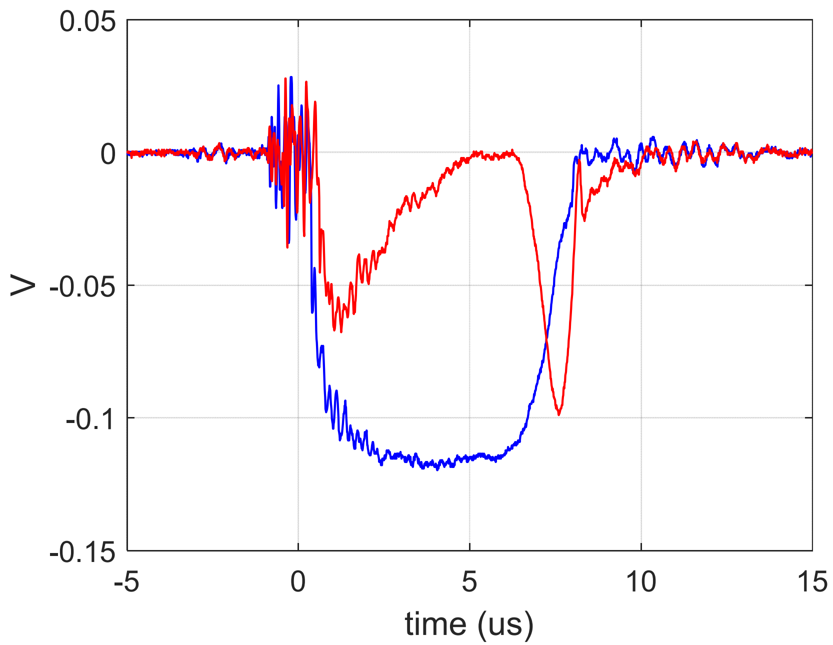




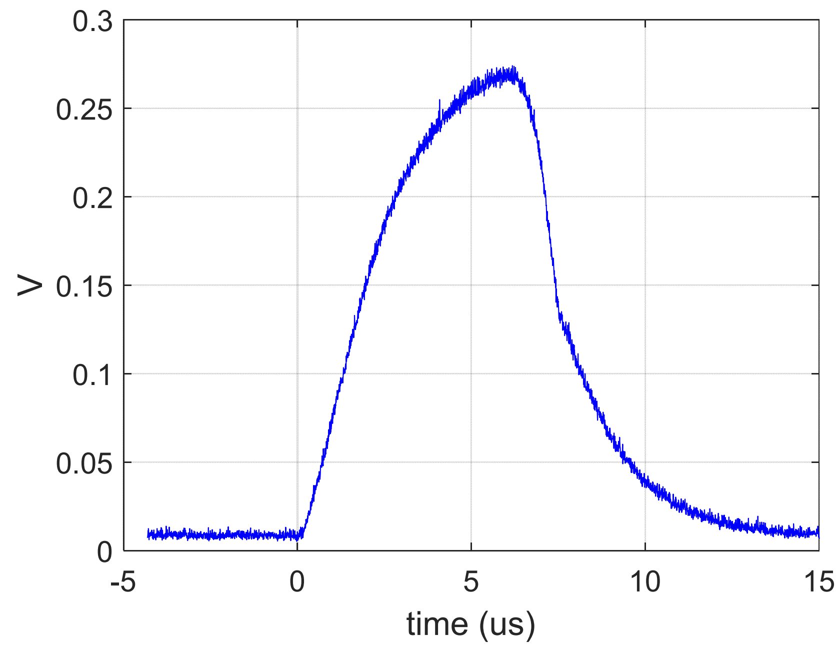
Vacuum: low 10^{-9} Torr
Repetition: 2 Hz
Duration: 5 μs flat top
Field for DFEA experiments: 10-35 MV/m

RF power and field in AWA gun

Forward (blue) and reflected (red) power detected by diode, flat-top ~5 µs



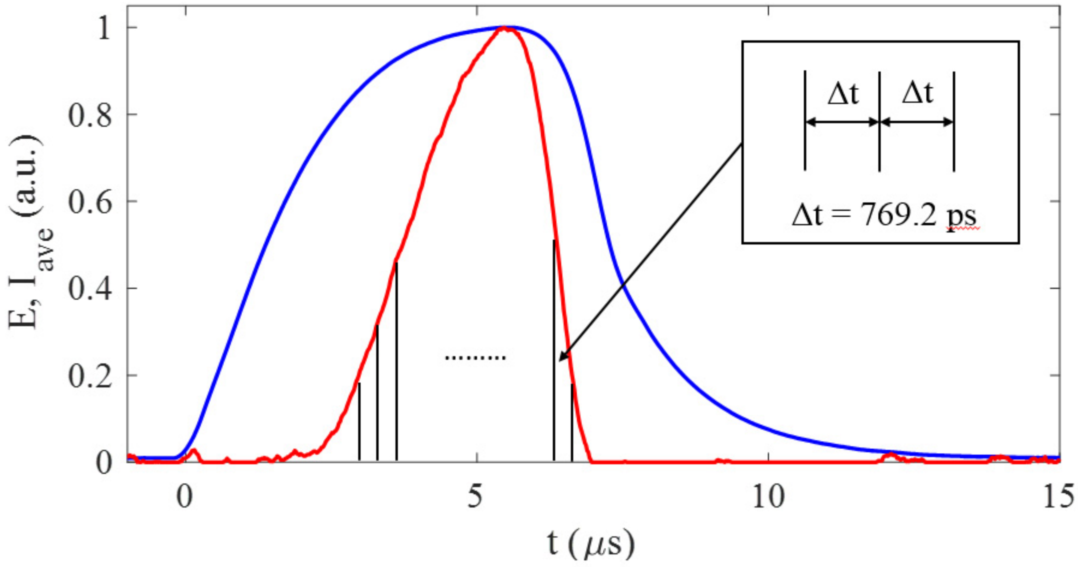
Field inside the gun measured by rf pickup antenna



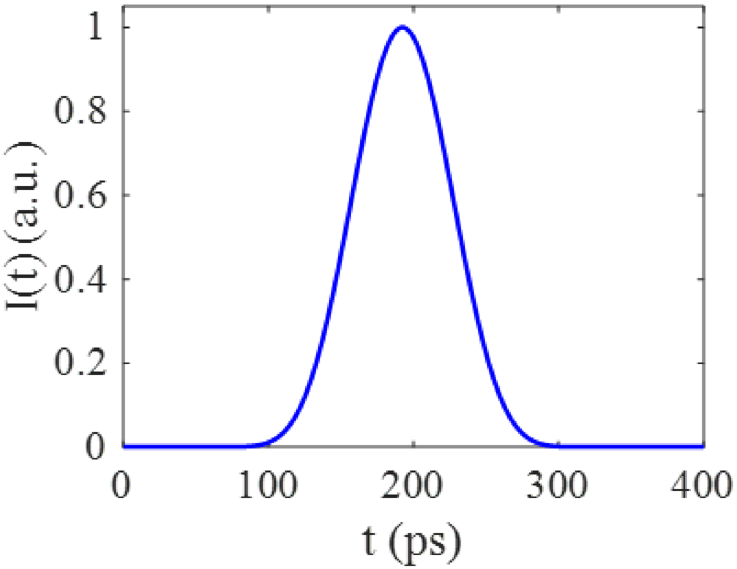
Estimation of emission current

Blue: macro pulse in gun

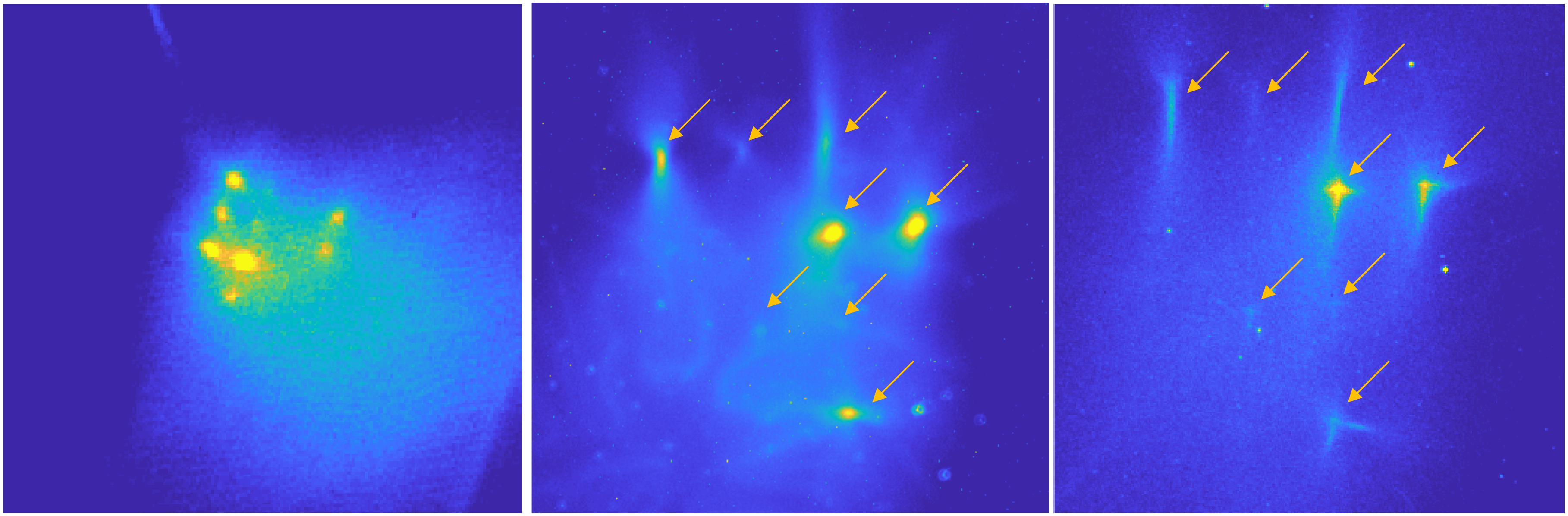
Red: derived emission current in the macro pulse based on FN enhanced emission model.



Derived micro pulse of emission current assuming sinusoidal rf



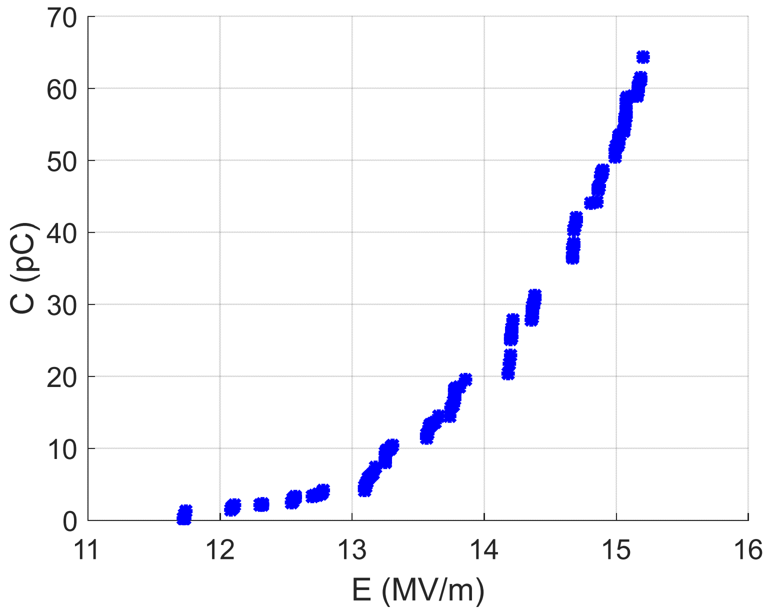
Images from sparse array show pattern creation and transport

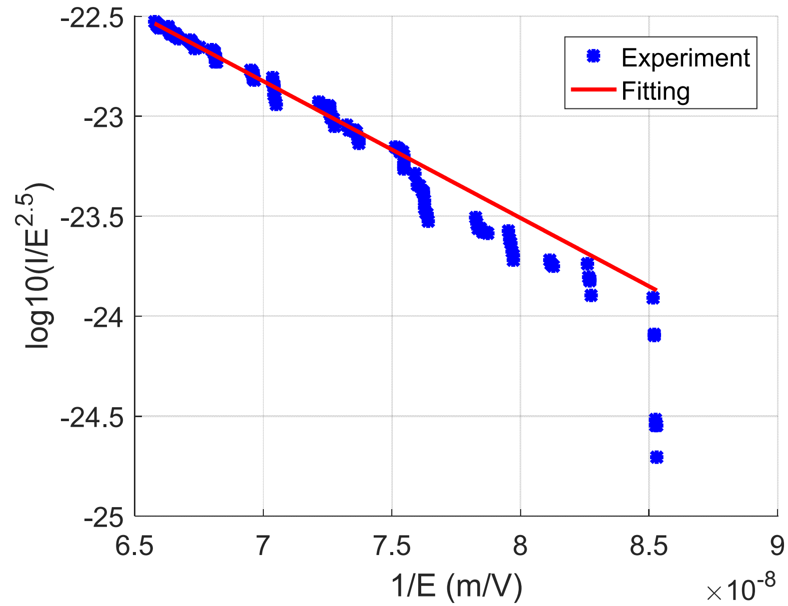


YAG1	YAG2	YAG3
14.9 MV/m	15.1 MV/m	15.1 MV/m
Magnification: ~2	Magnification: ~7	Magnification: ~10

Rotation between YAG1 and YAG2 from beamline solenoid.

IV curves and analysis from sparse array

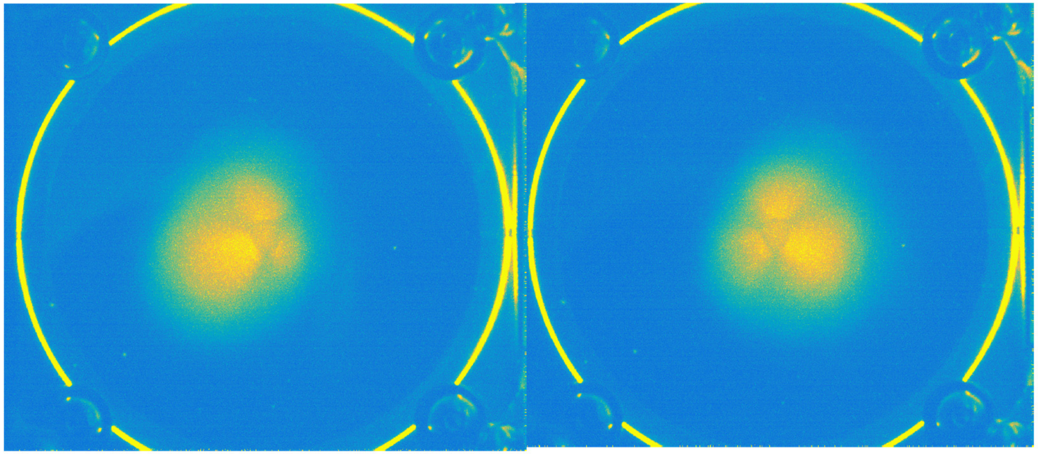




- FC 2 time constant ~5 ms
- 60 pC bunch charge at 15.1 MV/m on FC2
- Linear region of FN plot (left) yields β of 450, (φ of 4.9 eV measured)
- β gives effective emission area of 5490 nm^2, or about 25 nm on a side per tip.
- Peak current/tip = 25uA

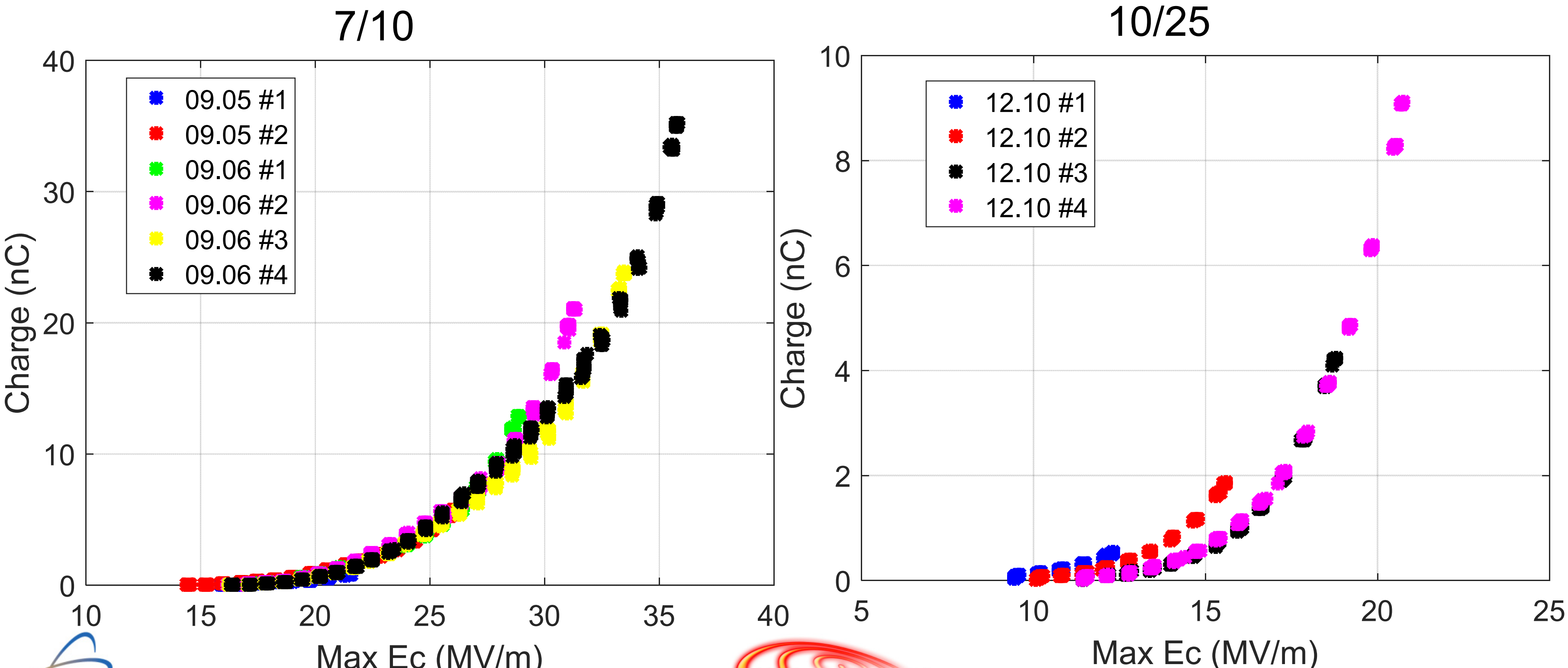
YAG Imaging of CAT1 and CAT2

- CAT1 and CAT2 arrays were off-center on the cathode plug
- Likely issues: YAGs charging, high space charge, YAG damage, array centering.
- Beam pattern on YAG was distorted and vanishing when adjusting trim magnets.
- We were able to use the solenoids to eliminate edge emission downstream – important for taking IV curve on FC2



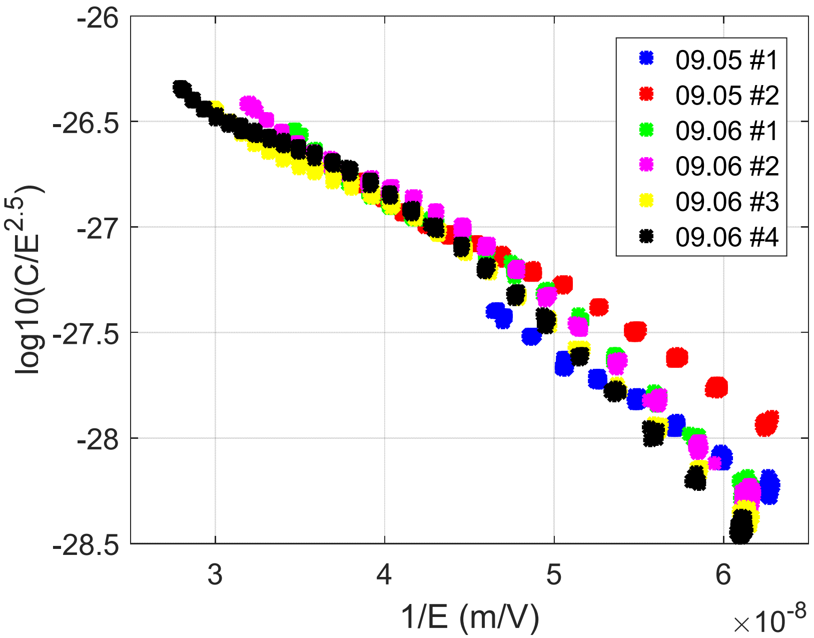
IV curves for 1 mm triangle array indicate pyramid size/pitch dependencies

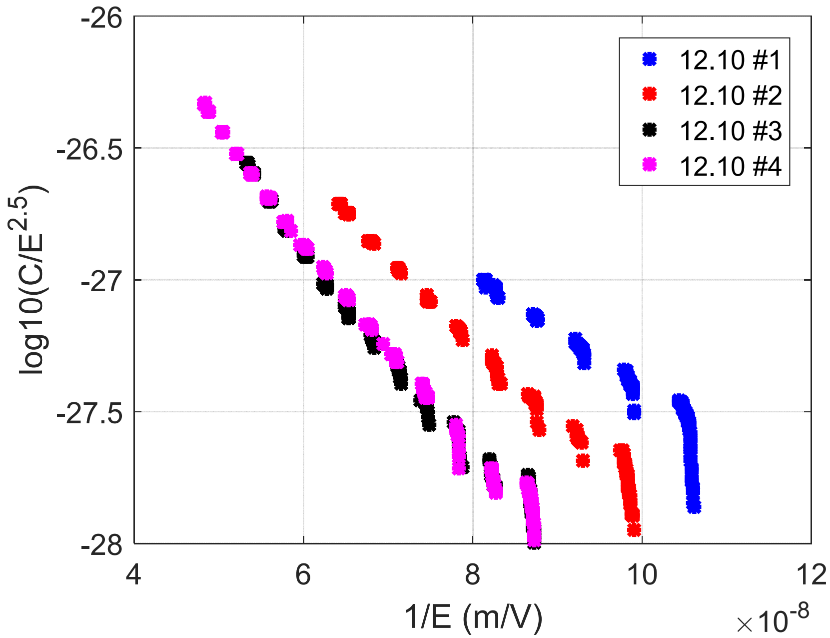
- Denser array (7/10) shows lower total charge at the same field compared to the sparser array (10/25)
- Larger pyramids show lower damage threshold



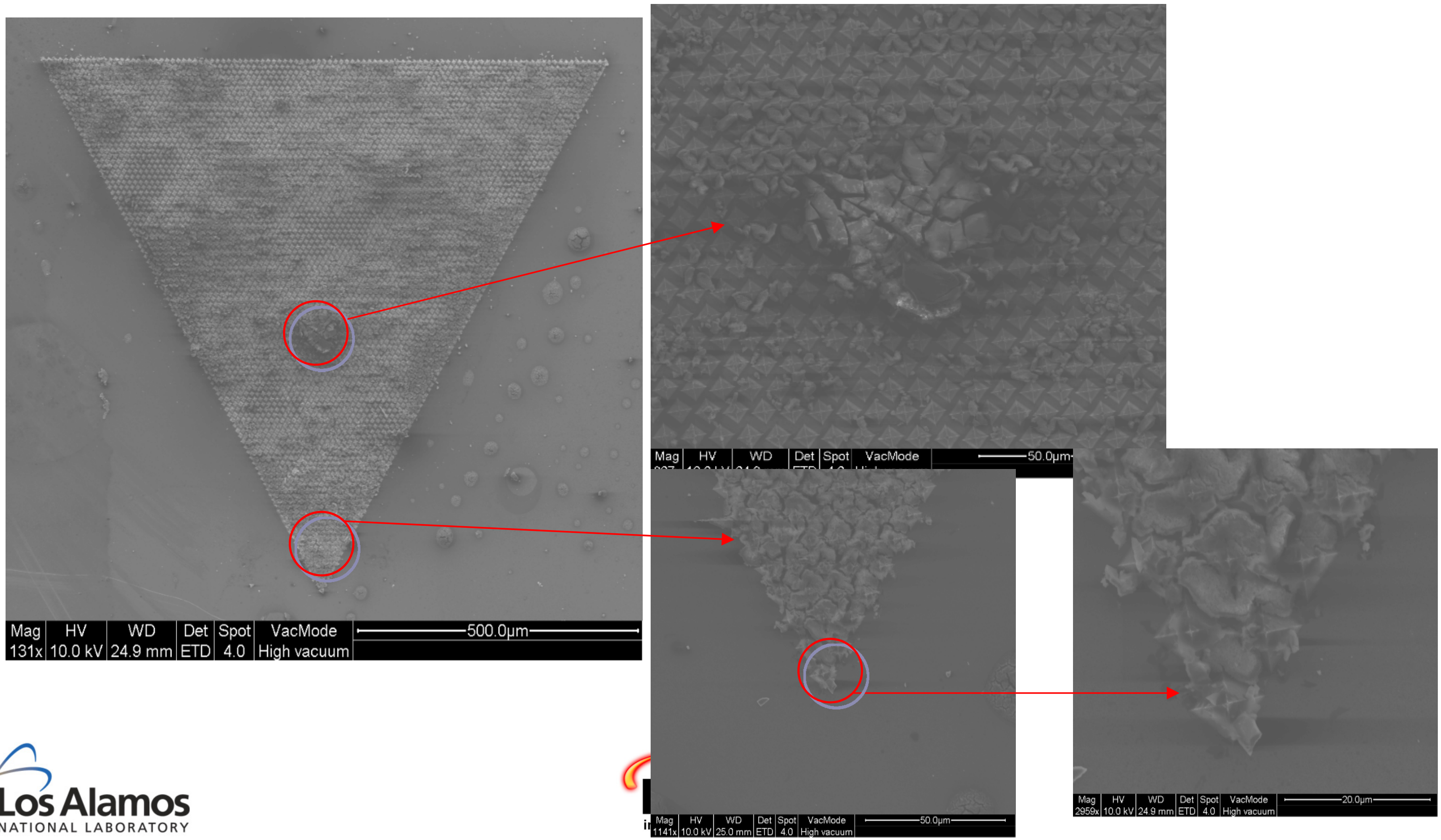
IV curves plotted in FN coordinates show non-linearity

- Non-linearity can be observed at high field end with two bends, bending positions vary

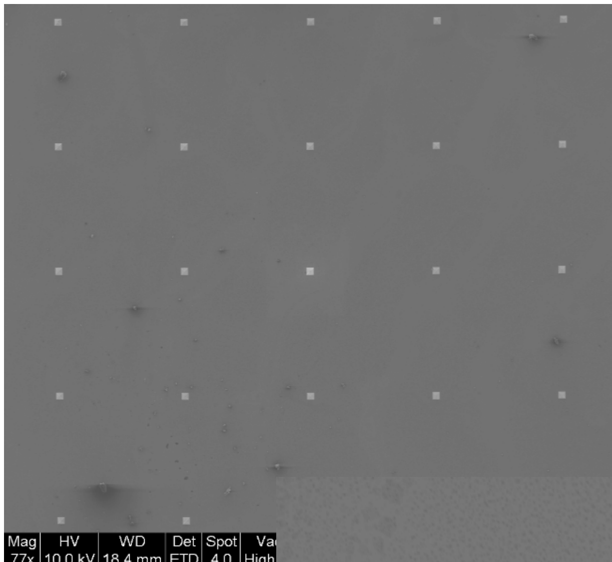


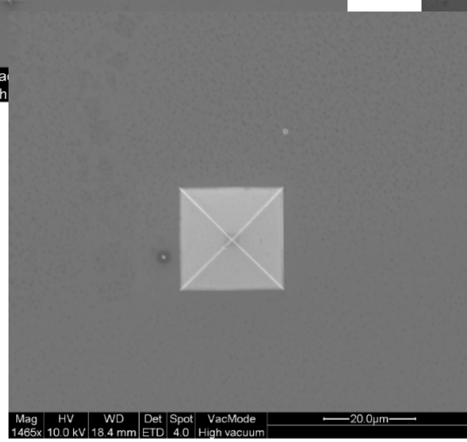


At sufficiently high field, arrays can sustain significant damage

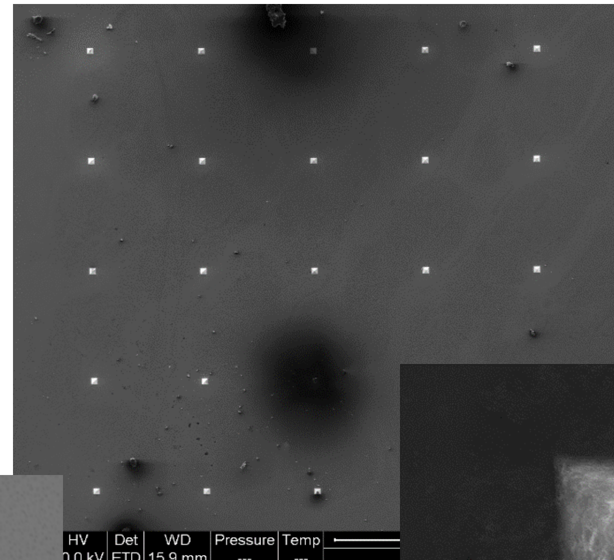


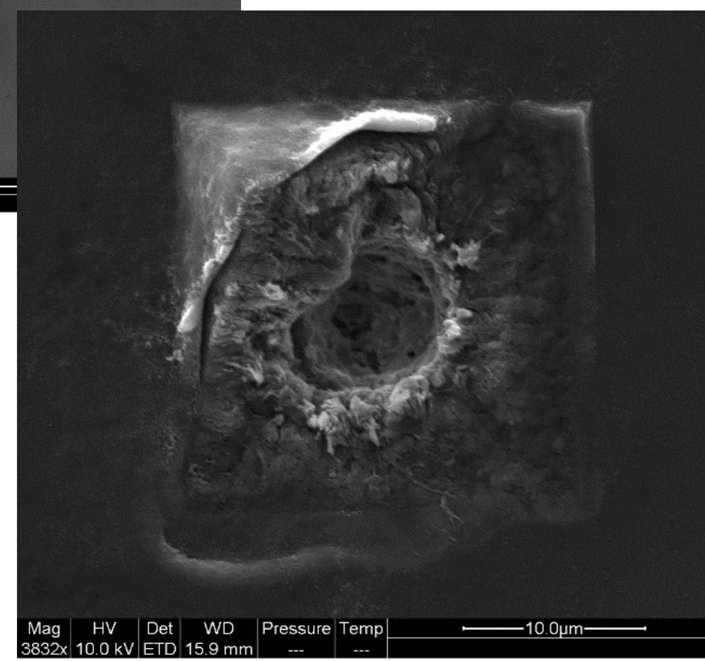
At high field, a small defect at the base of large pyramids can lead to damage





before





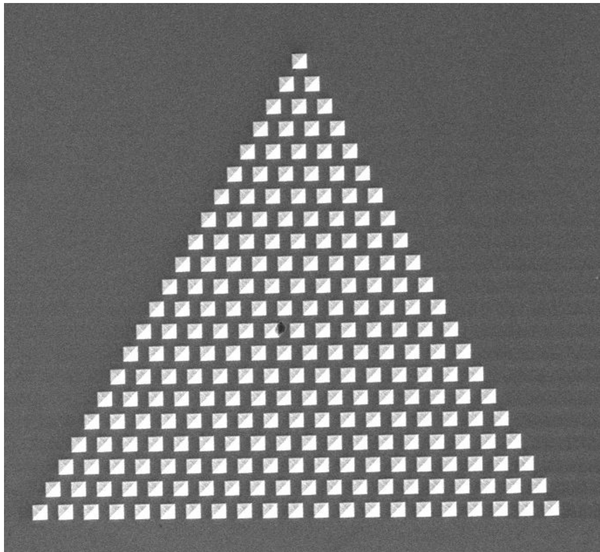
after

Los Alamos NATIONAL LABORATORY EST. 1943

LDRD innovation for our nation

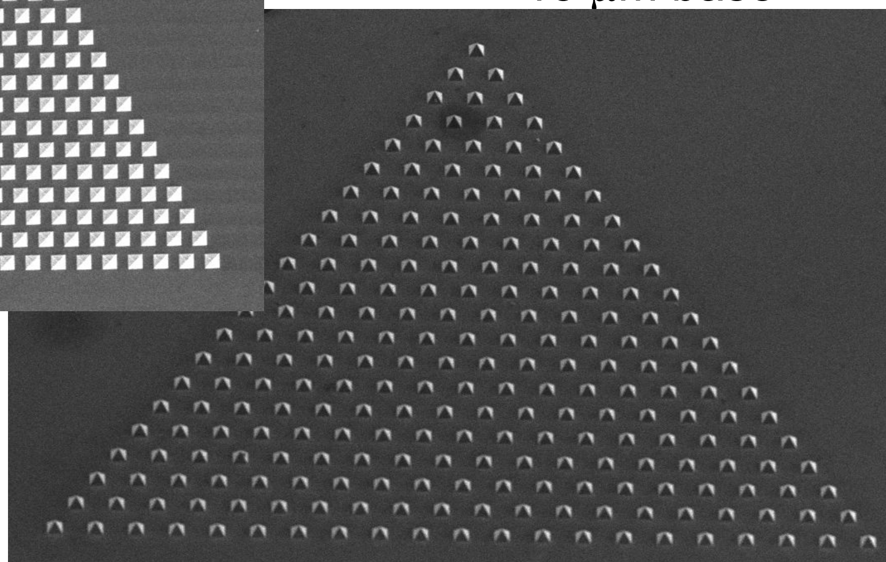
Future plans include different pyramid height at the same pitch

We are going to test the effect of tip height using 5, 15, and 25 µm base pyramids all at 50 µm pitch.

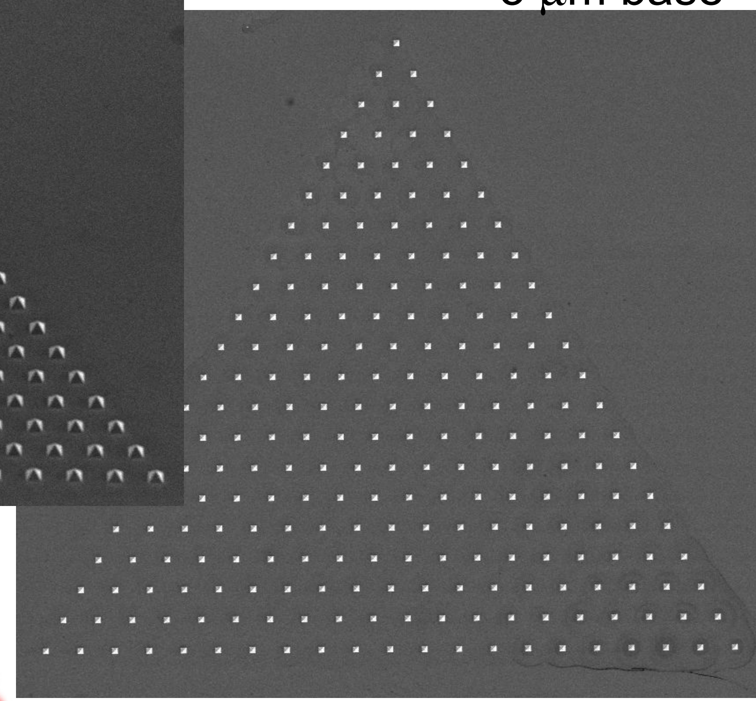


25 µm base
TESTED

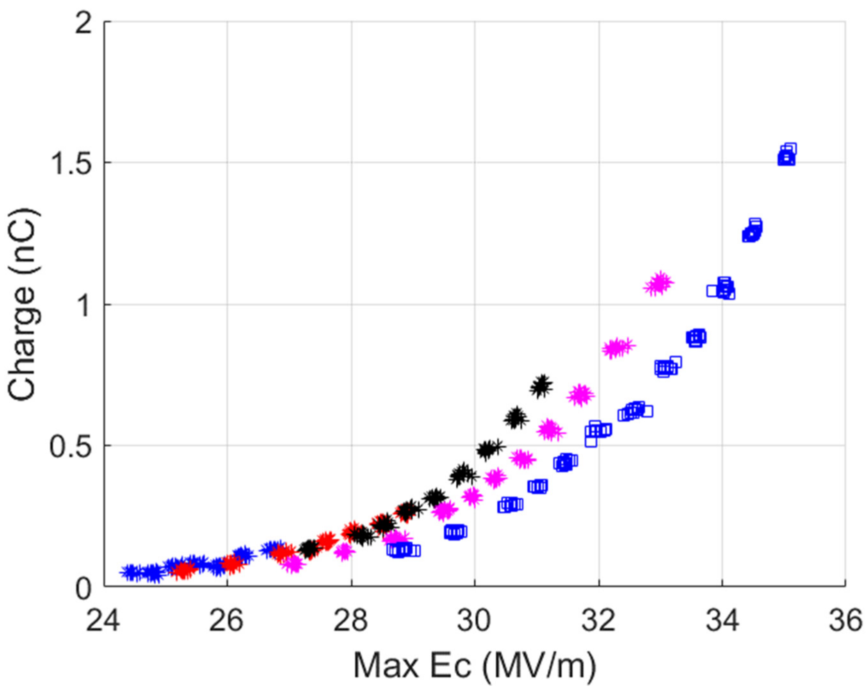
15 µm base



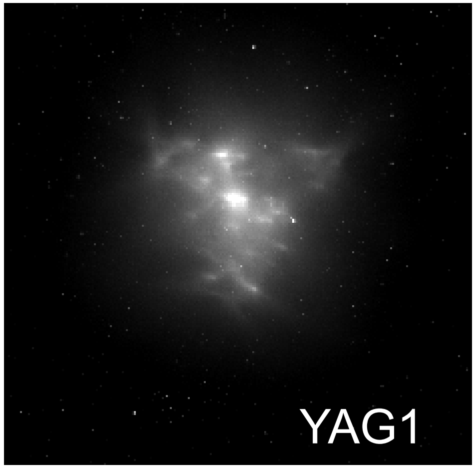
5 µm base

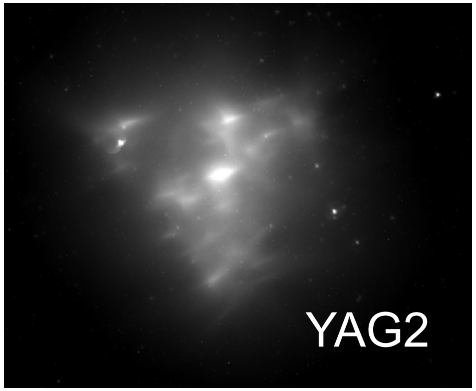


CAT 3 – (25um/50um 1mm triangle array)



Tested 8/24-8/25!





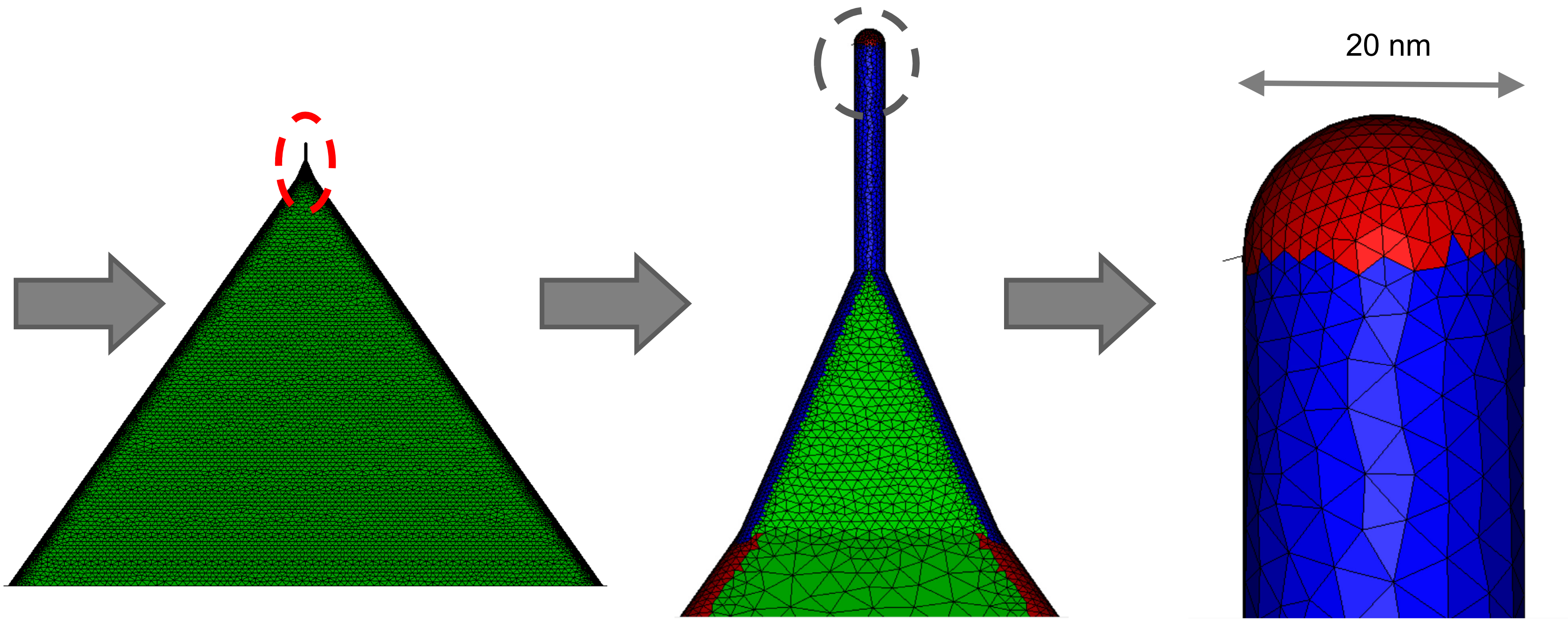
- 5us flat top
- assume 100 emitters
- assume 20% of marcro pulse emitting:
- 1.5mA array current
- 15uA per emitter.

Simulations

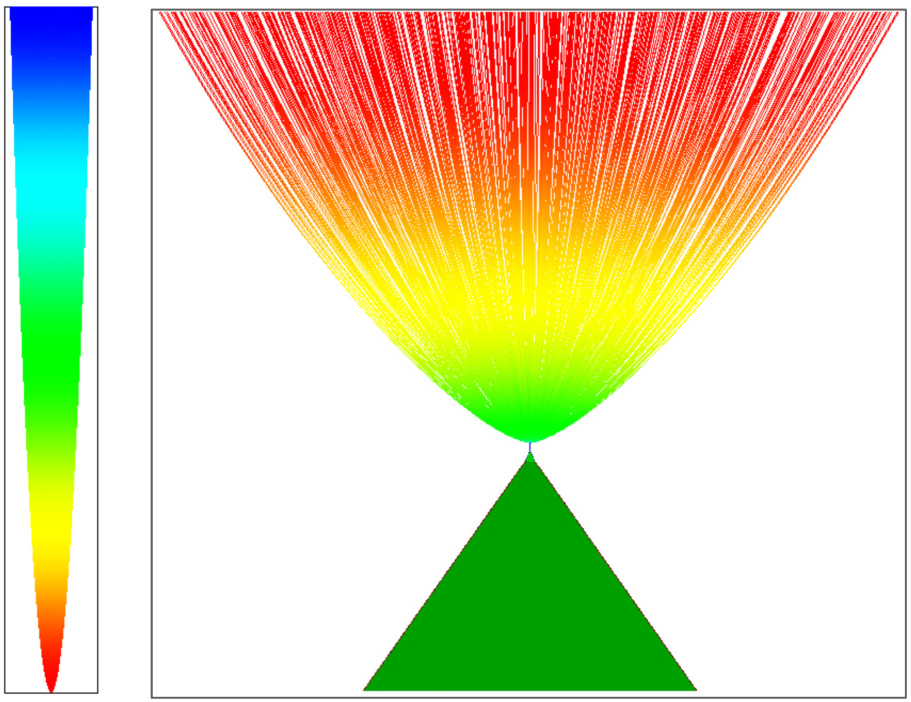
- Set up in MICHELLE gun code
- Modelling of individual Emitters
- Modelling of array elements interactions
- Shielding Effects from Simulations

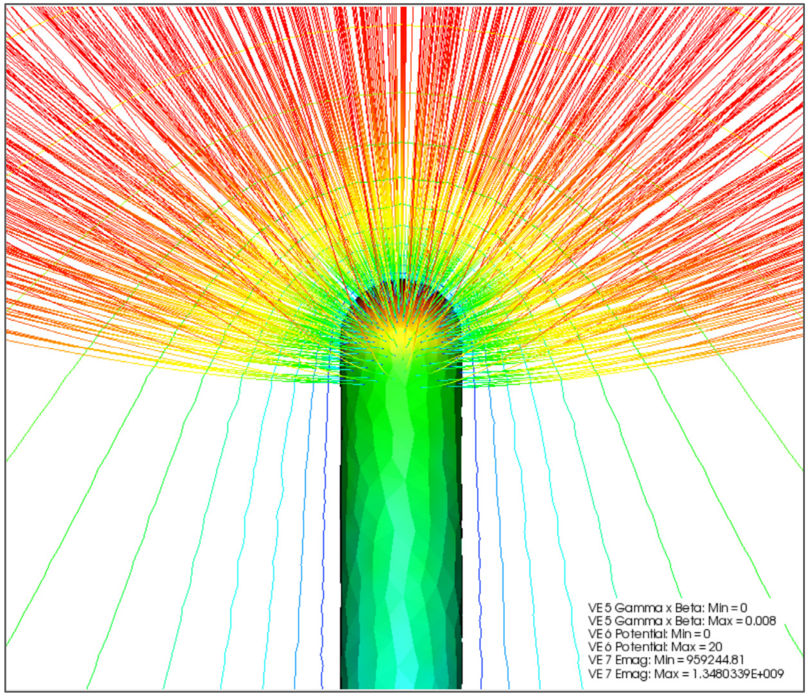
Simulations – cont.

- Largest to smallest element size ratio: 14 um /1.3 nm ➔ 10,000:1



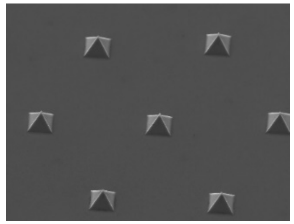
Particle Trajectories / Potential / E-Field



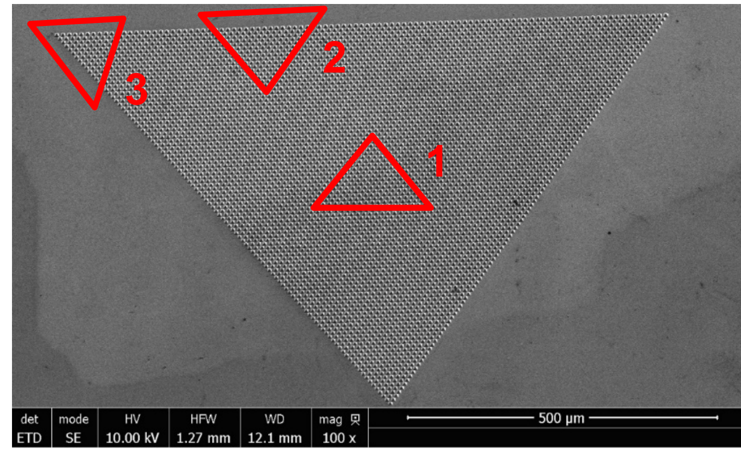


Courtesy of Dr. Kim Nichols, LANL

Simulating Arrays



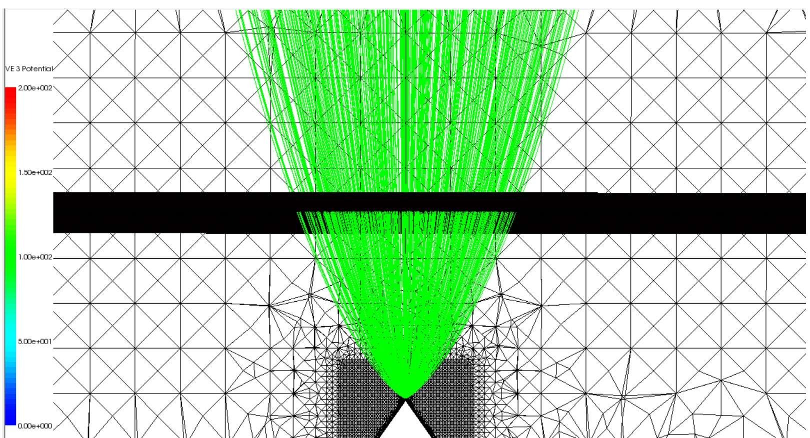
Dense Array:



Sparse Array:

- Export the beam on an equipotential plane – at 200V, 20 um, there is less than 0.1% variation over the plane.

- Import Slice Beam Data into Python script that copies and translates original beam onto grid.



*Able to use cluster at Leidos the week of November 26th to get these meshes done.

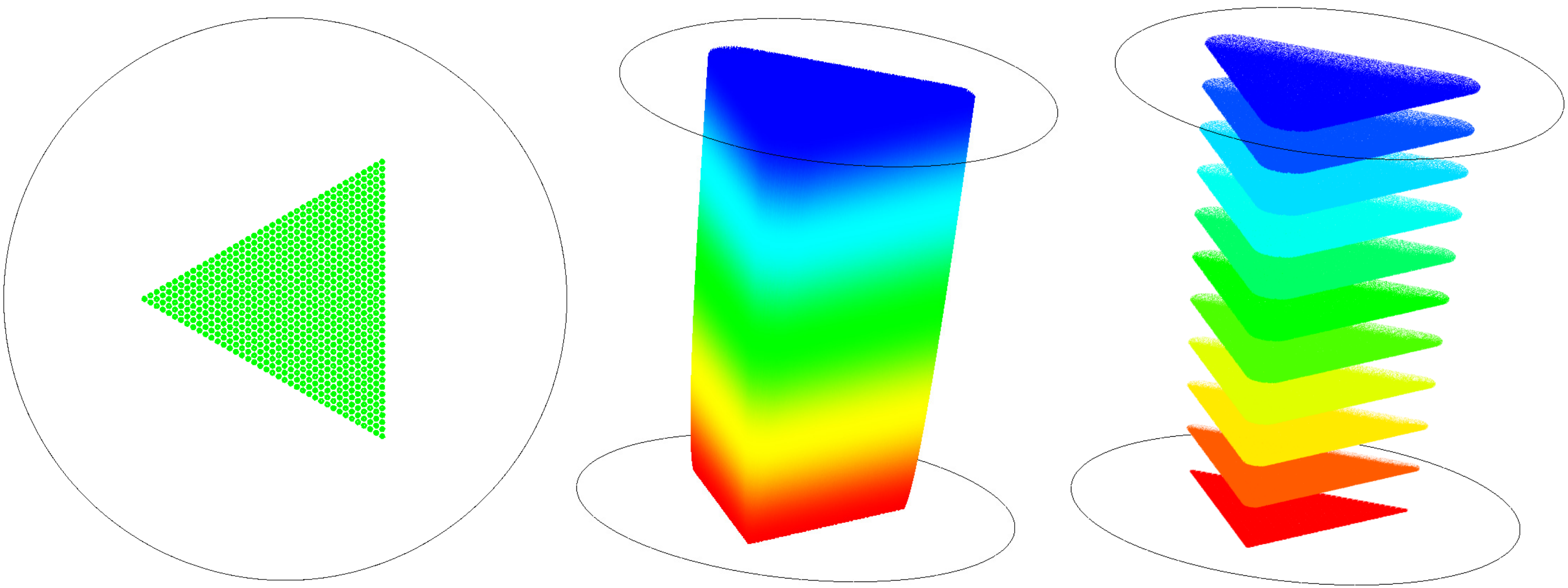
1.) interior elements simulated in their array pattern using symmetrical boundary conditions.

2.) edge elements simulated using symmetry on 2 sides, space on third side.

3.) triangle ‘point’ elements simulated using symmetry on 1 side, space on two sides.

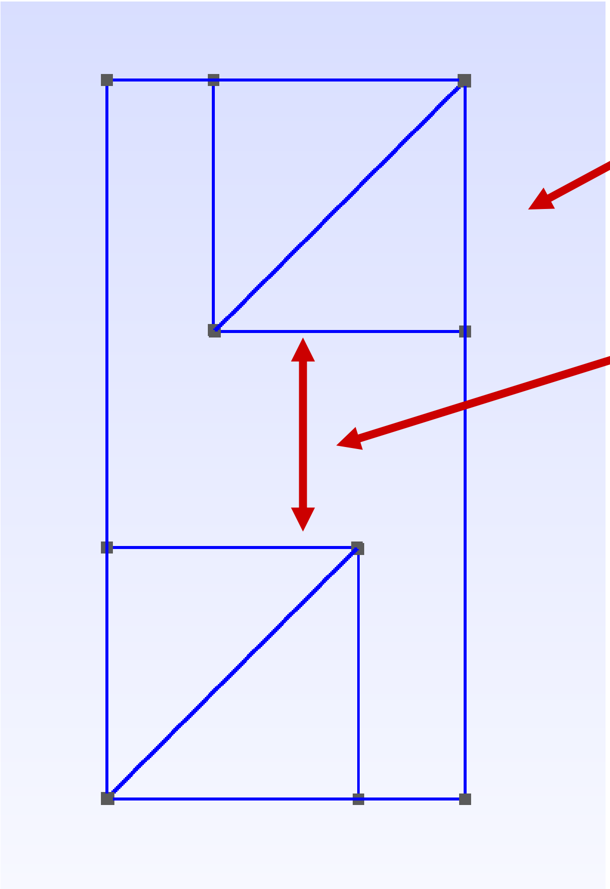
Individual Beamlets are Imported to Model array

- **Particle Trajectories Colored by Kinetic Energy**



Courtesy of Dr. Kim Nichols, LANL

Element interactions modelling



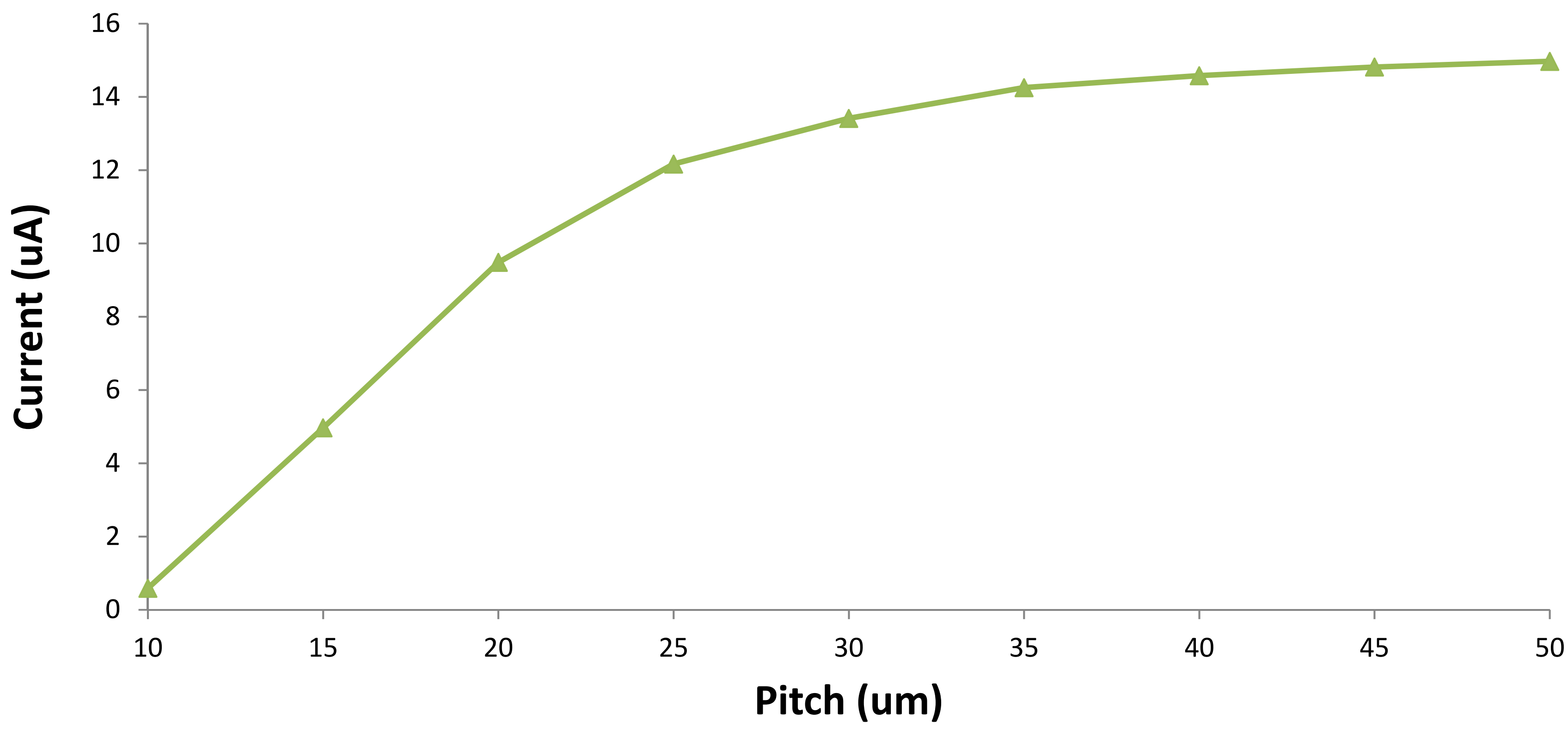
¼ emitter

Neuman Boundary Conditions

Variable pitch

Infinite Sea of Emitters

Shielding Effects of Emitters – 7u base



Conclusions

- We have produced and transported shaped beams from a variety of DFEAs in an RF gun
- We see greater bunch charge from more sparse arrays, suggesting shielding and space charge contribute significantly
- We are currently investigating different pyramid sizes at the same pitch (5, 15, and 25 μm base, 50 μm pitch).
- We need more experiments to determine optimum geometry for high current and robustness.

Thank you for your attention!

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