Shaping Electrostatic Conditions in the Stalk of the ERL -750 kV Electron Gun

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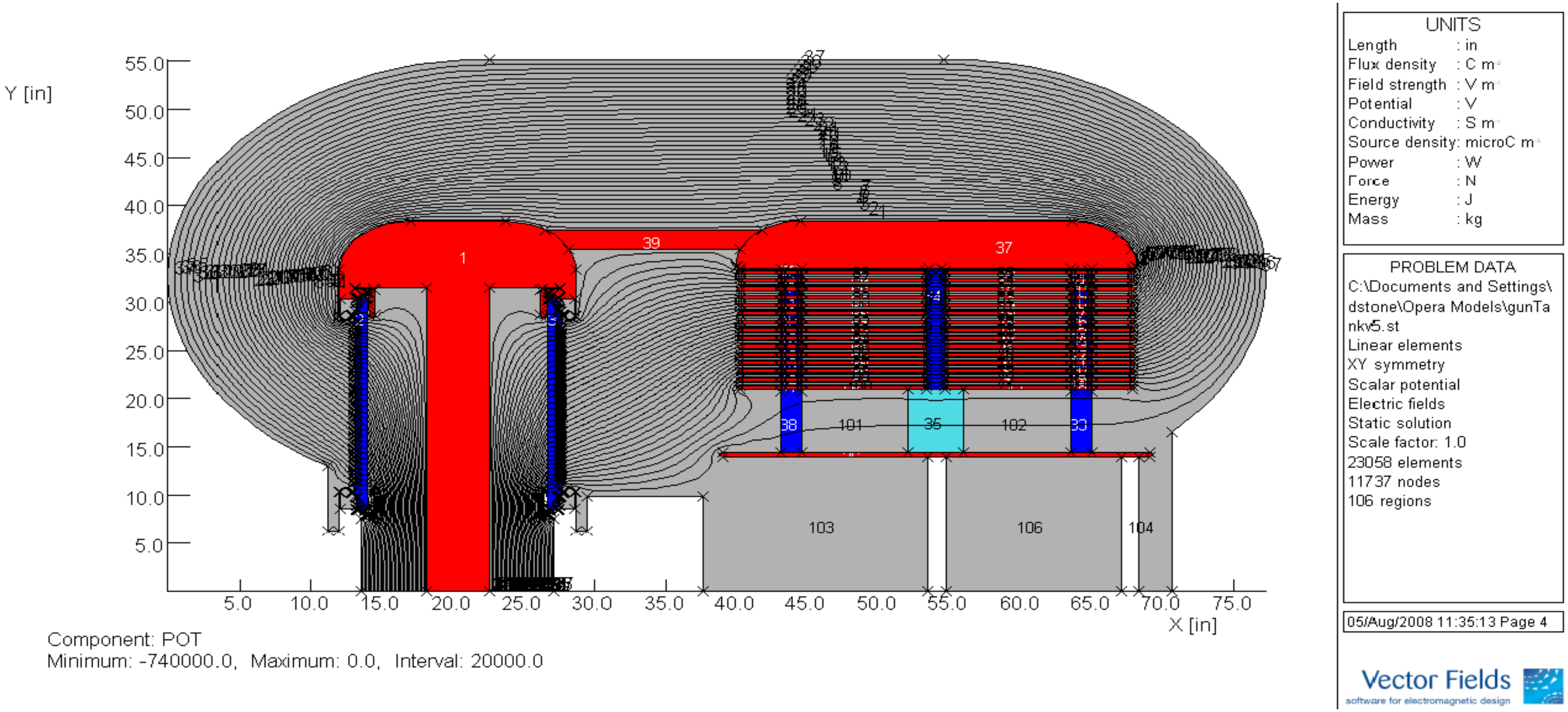
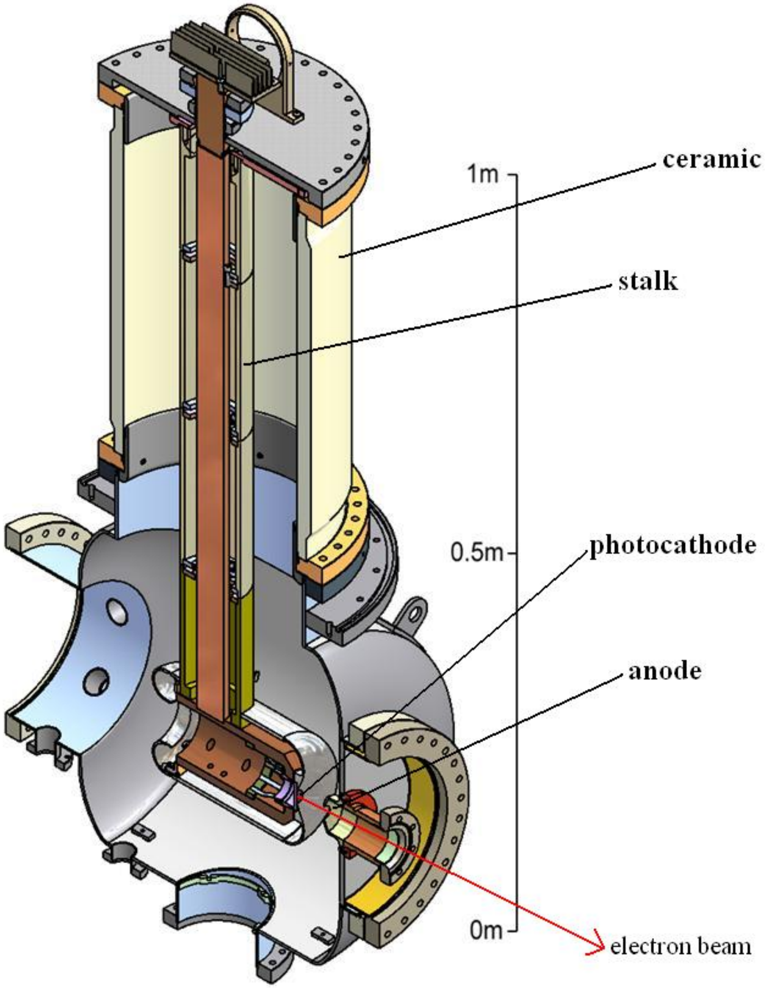
Full Gun Apparatus



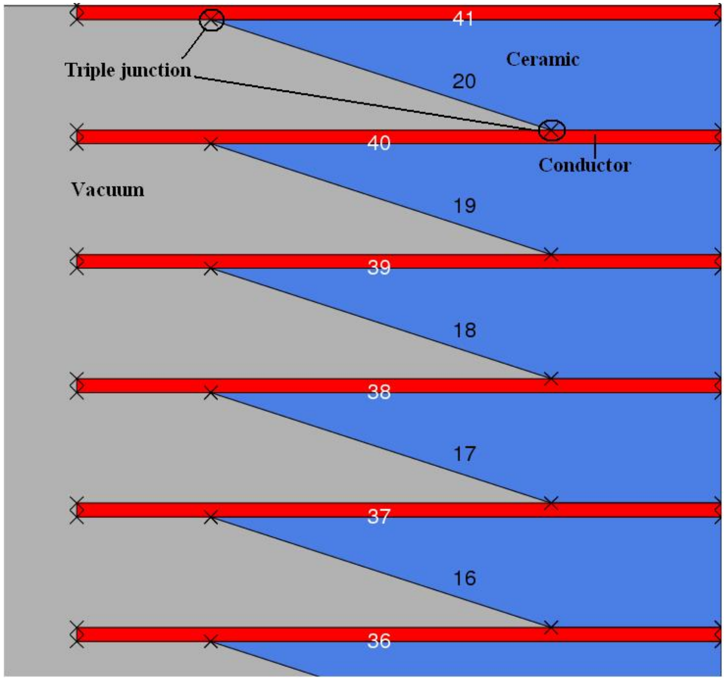
- -750 kV power supply (left), electron gun (right)
- SF_6 tank ($\varepsilon_r \approx 3$) surrounding power supply and gun (held at ground), about 1.4 m tall
- Highest fields at corona rings protecting triple junctions inside ceramic
- Equipotentials unevenly distributed throughout apparatus

Gun Details

- Electron gun:
  - Photocathode, pulsed laser, stalk, ceramic under vacuum
  - Cathode at -750 kV w.r.t. anode/electrode chamber
  - 2 ps laser pulses centered on photocathode (GaAs), produce beam to be powered to 100 MeV with 100 mA current
  - Ceramic (alumina, $\varepsilon_r \approx 10$) a single corrugated cylinder
- Cathode Voltage
  - Cathode must use conditioning, HPR, electrochemical polishing, etc. to decrease imperfections



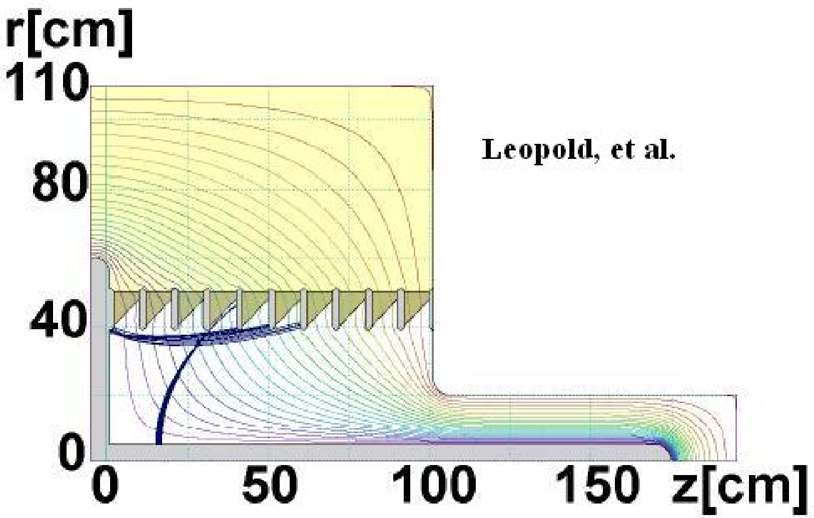
Problems

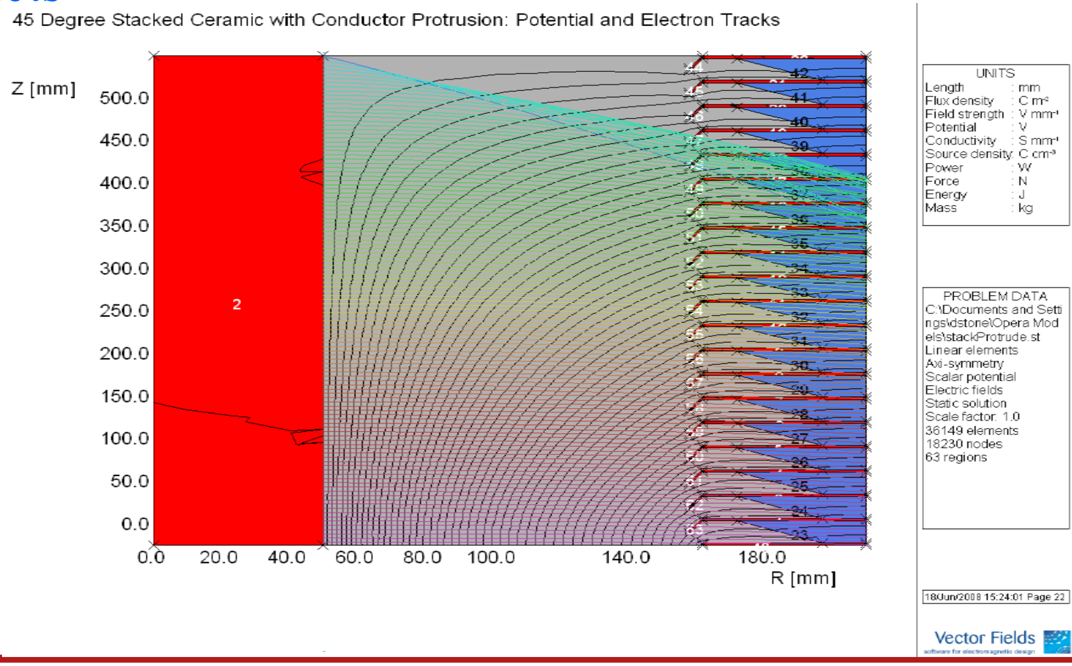


- Ultra-High Vacuum (UHV)
  - Maintained to prevent voltage breakdown- desorbed or leftover gas can initiate breakdown
  - In gun, p $\approx 10^{-11}$ torr to prevent decay of QE in photocathode
- High Voltage (HV)
  - Breakdown occurs in most gaps w/ excess field strength > 20 MV/m
  - Initiated by microprotrusions and other e^- emission sites, strong fields at triple junctions, desorbed gas, small gap separations, etc. (excessive surface area exacerbates these problems)
  - Once initiated, if electron current impacts ceramic, secondary emission and electron avalanches can occur, irreversibly destroying ceramic

Preliminary Designs

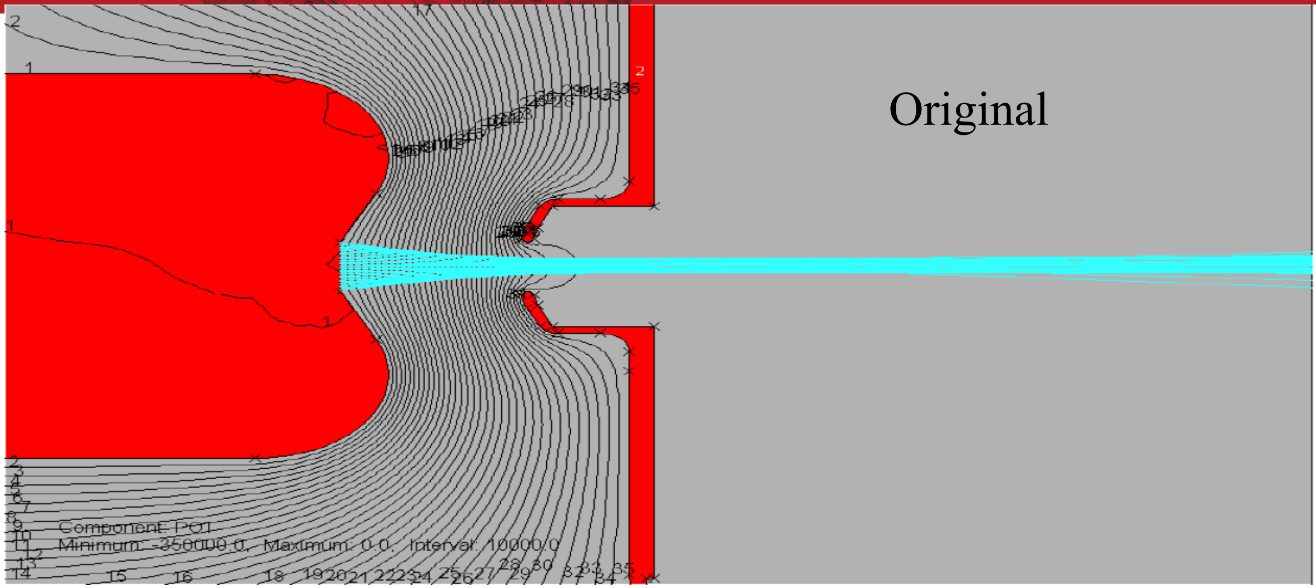
- Ceramic Design
  - Stacked/graded insulator design (J.G. Leopold, et al.)
    - No noticeable variation in field with variation in ceramic angle
    - Insignificant shaping of field with conductor rings separated by linear potential steps
    - Conductor rings suggested by others (Sinclair, Haimson, etc.) used to protect ceramic from electron impacts

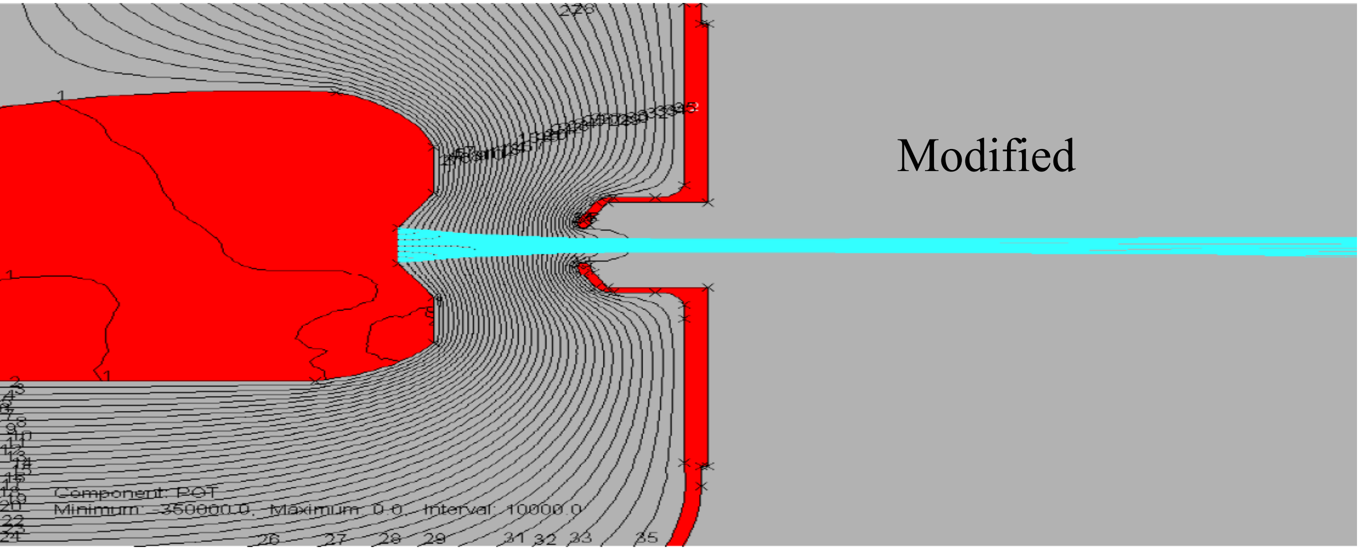




Side Project: Cathode Shaping

- Surface area reduction
  - Reduced curvature of Pierce Electrodes surrounding photocathode

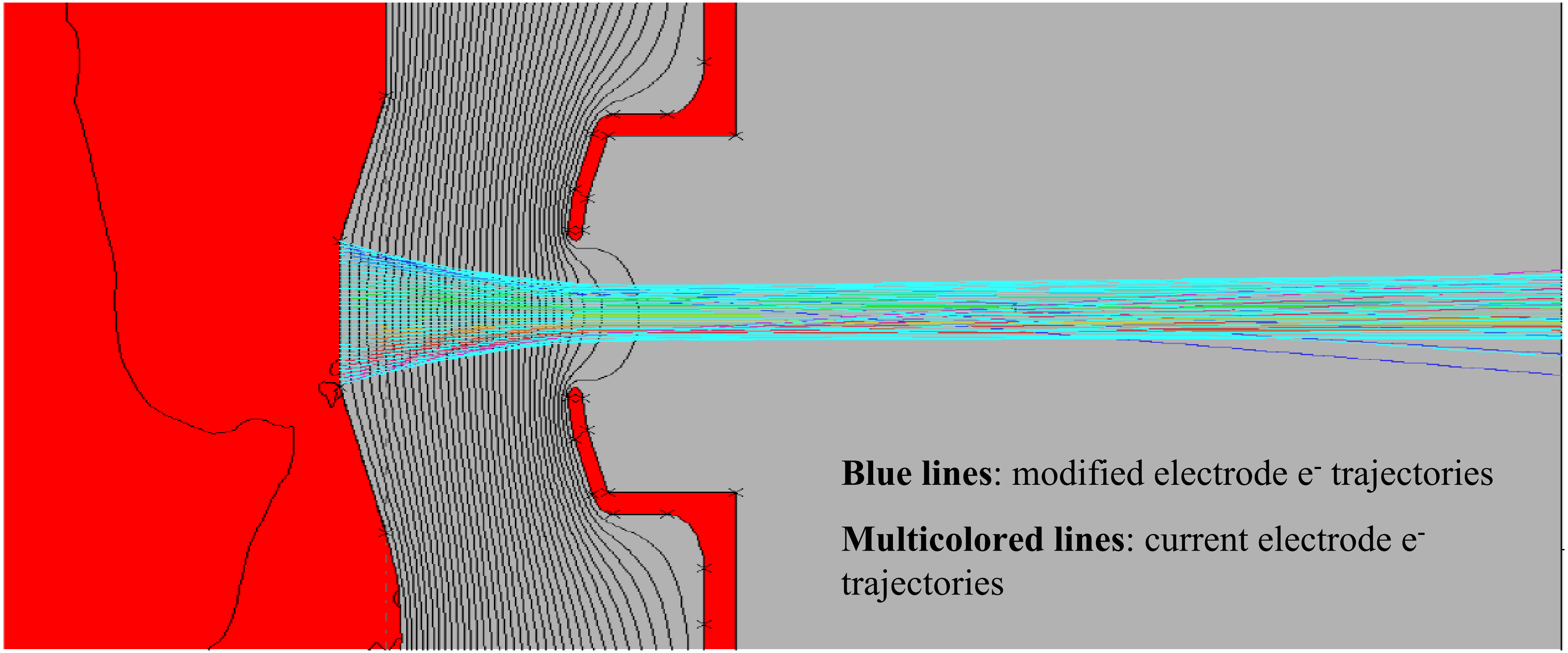




- Curvature reduction
  - Decreases local field enhancements

Side Project: Cathode Shaping

- Minor improvements in modified design
  - No quantitative measurements able to be taken
  - Less aberrations in beam path, a more uniform e^- distribution, but wider beam
  - Space charge analysis not used



Blue lines: modified electrode e^- trajectories

Multicolored lines: current electrode e^- trajectories

Side Project: Magnetic Fields in Gun

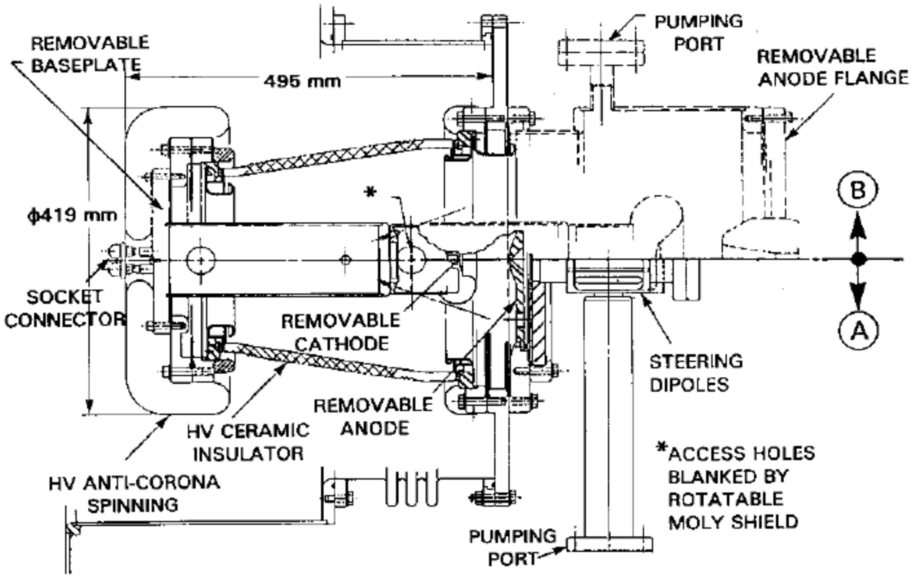
- Magnetic Fields
  - Use magnetic fields to deflect particles downward (φ-directed field) or in a spiral towards ground (z-directed field)
  - For z-directed field (solenoid field, helical e^- trajectory):

$$B = \frac{mv}{qr}$$

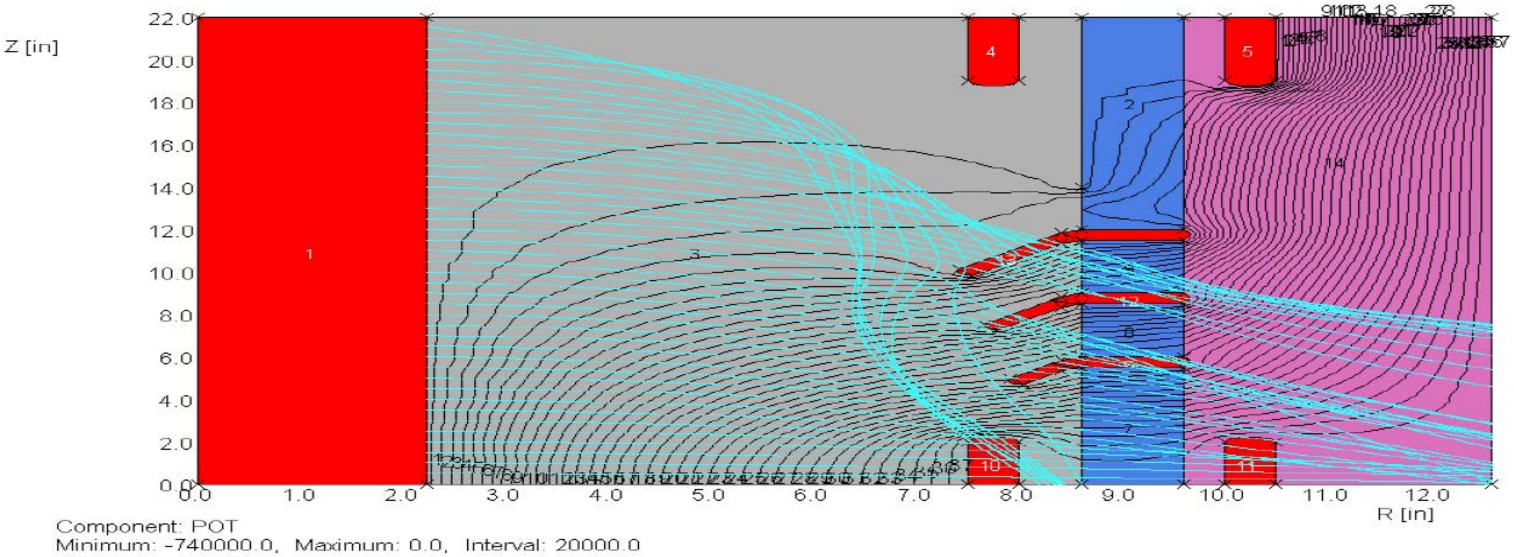
  - $m=m_e$, $v \approx .9c$, $q= -e$, $r = .16$ m
  - $|B| \approx$ 10-100 gauss
    - 4,000 to 50,000 wire turns around ceramic

Refocus on Stacked Ceramic Design

- Non linear potential steps and conductor ring separation
  - Discussions with Jacob Haimson (Haimson Research Corporation) and MIT PSFC
  - Two approaches to new design
    - Field curving design- use **E** field to entirely deflect e- towards chamber flange (ground)
    - Uniform field design- use uniform **E** field to evenly distribute e- over conductor rings protecting ceramic

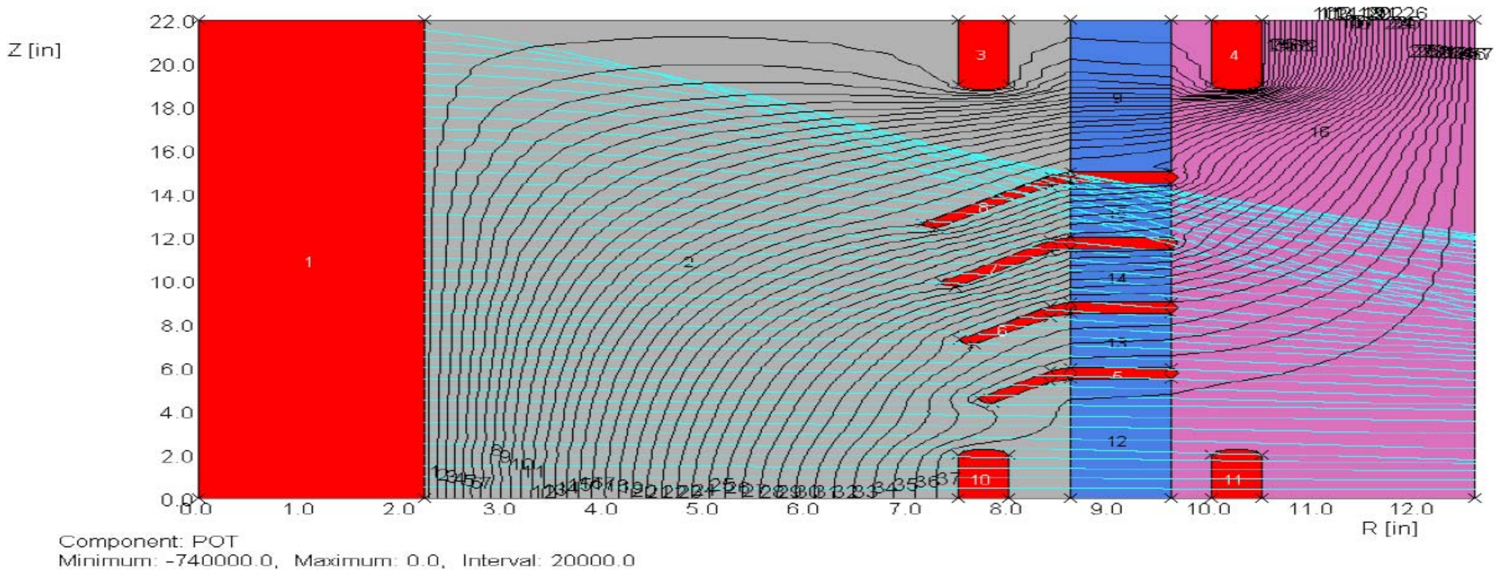


Refocus on Stacked Ceramic Design



- Field curving design

- Uniform field design
  - Note consecutive conductor rings are shorter to prevent secondary emission

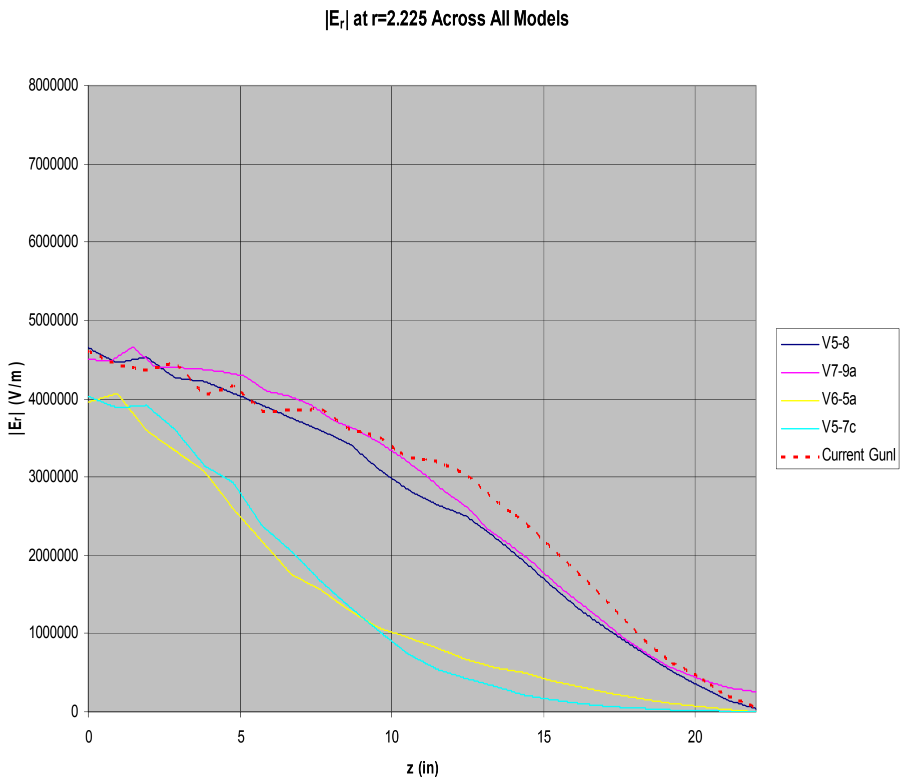


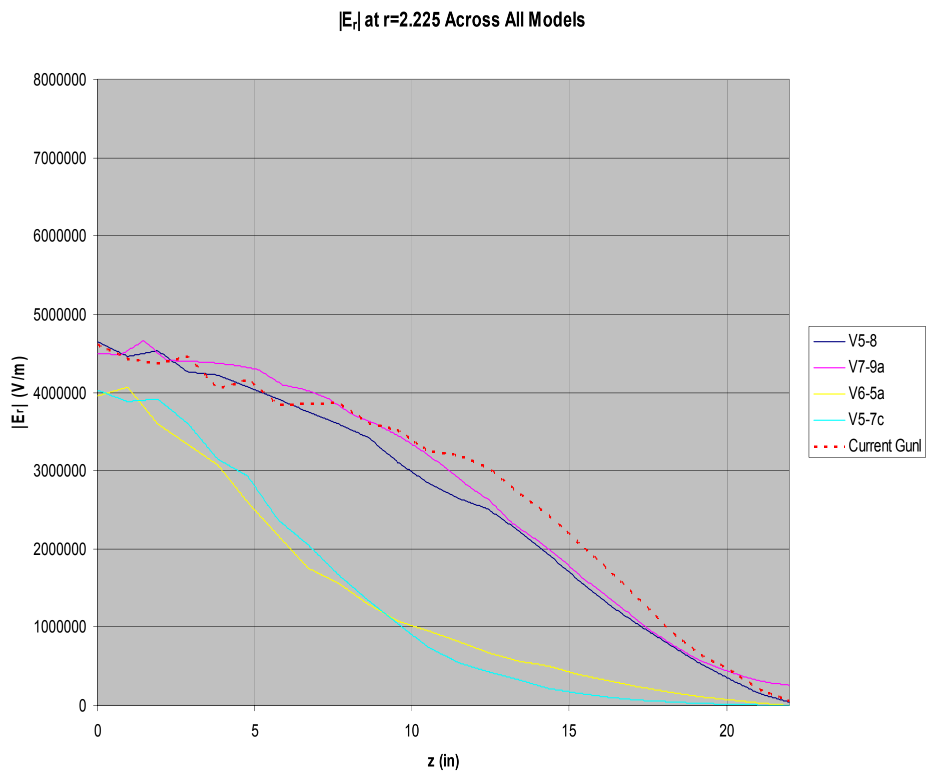
Refocus on Stacked Design

- Most efficient configuration determined by:
  - The value of $|E_\perp|$ or $|E_r|$, the magnitude of the perpendicular electric field component at the surface of the stalk. A greater perpendicular field component reduces the work function, φ, of a metal and increases field emission.
  - The value of ρ_e ($.5\varepsilon_0 E^2$), the electric field energy density in the stalk-ceramic configuration. A constant or symmetric distribution of energy density throughout the area of concern is desirable to reduce field enhancements.
  - The value of $|E_{max}|$, the magnitude of the maximum electric field strength at key locations in the configuration. High voltage breakdown, depending on the conditions, occurs around 20 MV/m in Cornell's gun case. It is attempted to keep maximum fields strengths below 12 MV/m in the models.
  - The engineering and machining feasibility of the geometry of the configuration. Limitations such as brazing effectiveness and metal machinability will constrain the models.

Refocus on Stacked Design

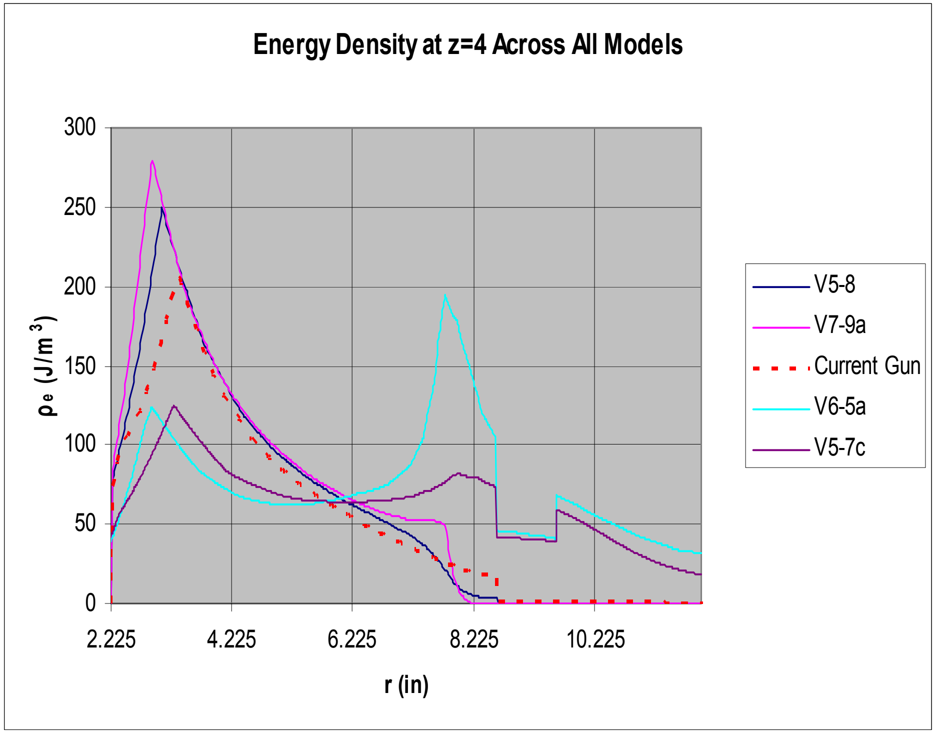
- **Comparison of |E⊥ | at r = 2.225 and r = 2.5**

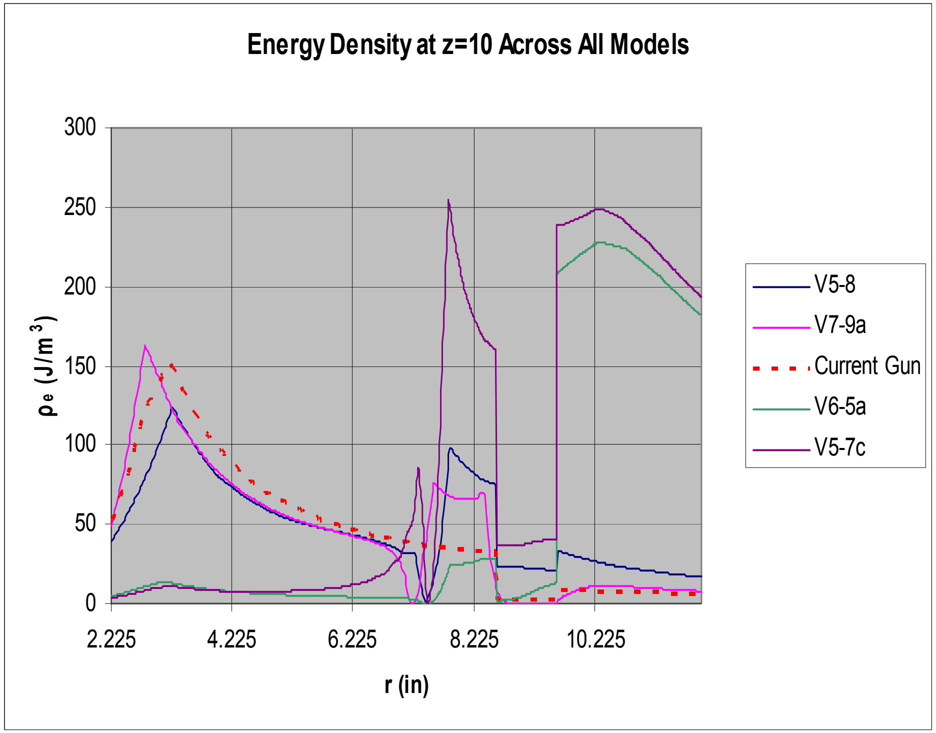




Refocus on Stacked Design

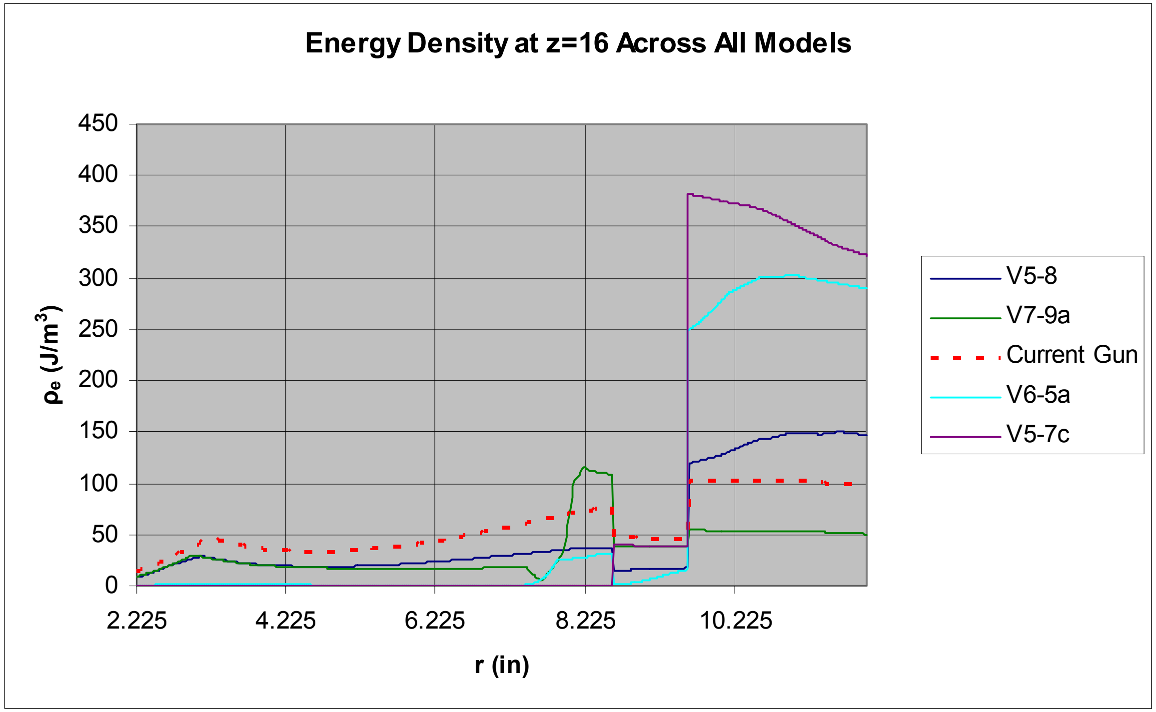
- **Comparison of ρ_e at z=4, z=10, z=16**





Refocus on Stacked Design

- **Comparison of ρ_e at z=4, z=10, z=16 (cont'd)**



Refocus on Stacked Design

- Comparison of maximum value of |E| at crucial locations throughout models

$|E_{max}|$(MV/m)

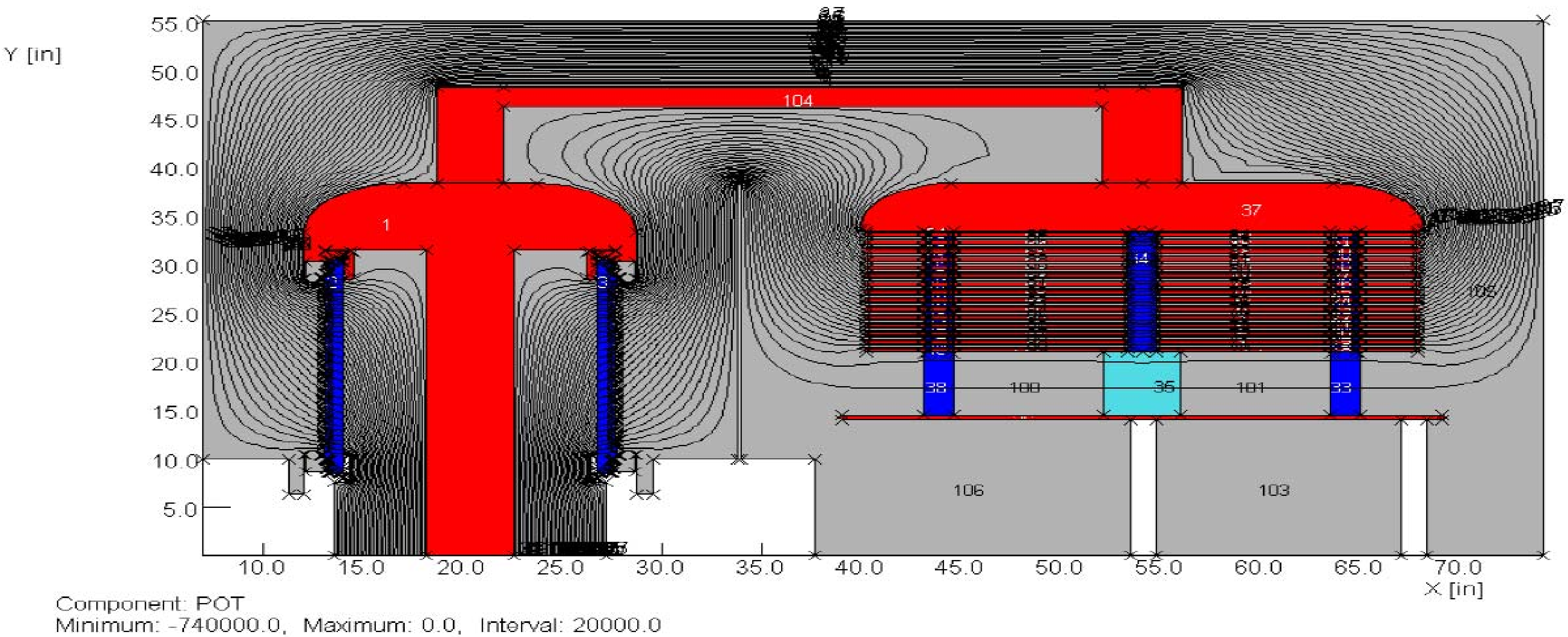
Location	r (in)	z (in)	6-5a	5-7c	7-9a	5-8	Original
Inner bottom ring	7.75	2.25	6.08	5.56	1.44	1.74	2.37
Outer Top Ring	10.25	18.75	11.6	10.8	21.3	17.0	17.3

Refocus on Stacked Design

- Model 5-7c (seen in previous slide) most advantageous
  - Uses metal coating/thin sheet at equipotential with stalk
    - Note: so far, any type of coatings on ceramics have failed
  - Electron emission likely to happen anyway, better to focus on deflecting electrons
  - Significantly decreased $E_{\perp}$ at surface of stalk
  - Lower, more constant energy density distribution
  - Lower average maximum value of $|E|$ at critical points
  - Decreased amount of conductor rings ->less brazing

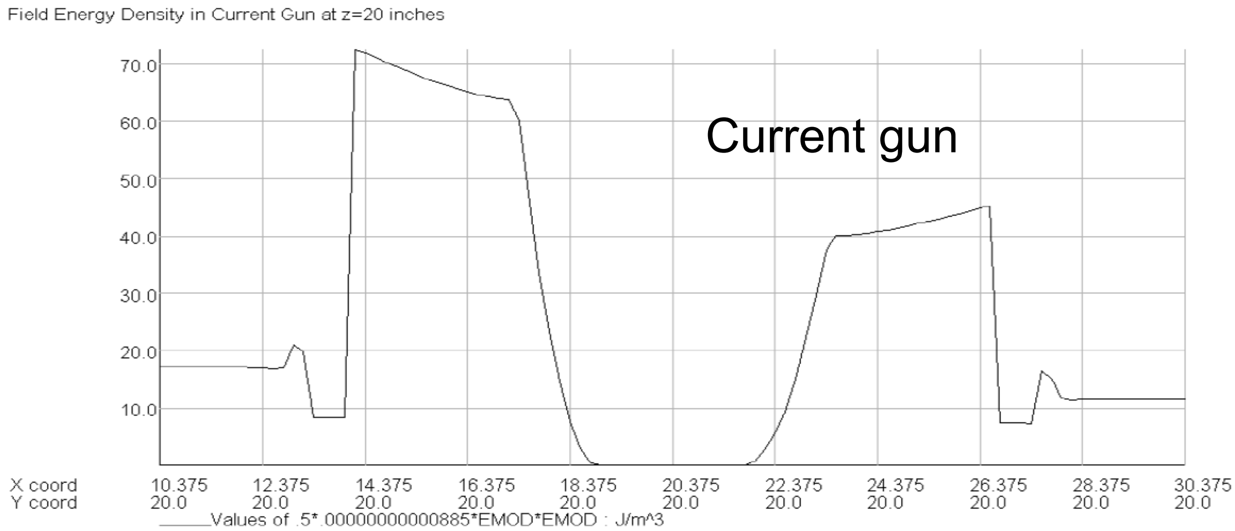
Side Project: Uniform Energy Density Distribution

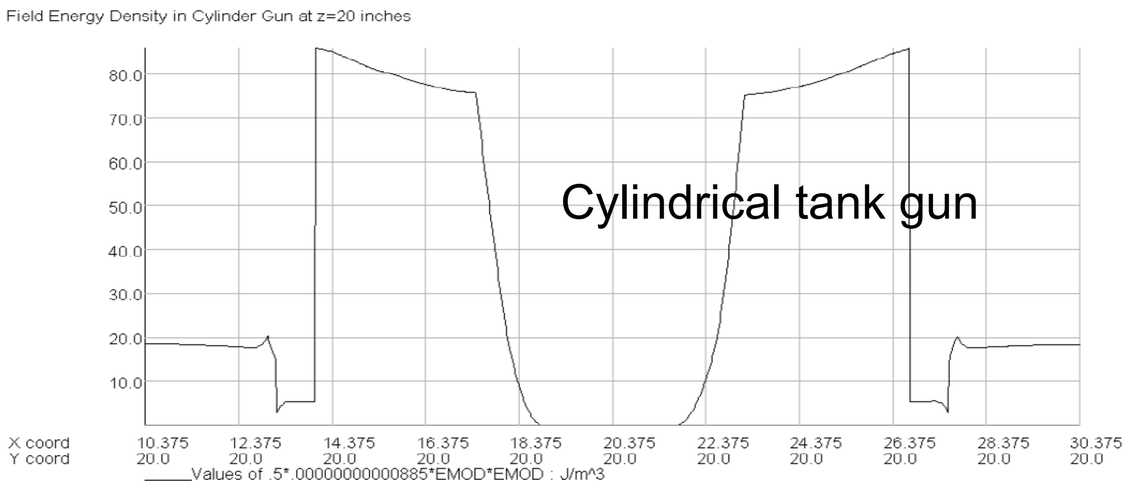
- Can increase field energy density uniformity by compartmentalizing gun and power supply in cylindrical tanks



Side Project: Uniform Energy Density Distribution

- Comparison of ρ_e in current gun model and cylindrical model





Conclusion

- ERL just getting underway
  - Will need new, more robust gun for further phases
  - Modeling done provides foundation for understanding designs and constraints involved in newer high voltage guns (including stalk/ceramic configuration and cathode surface area reduction)
  - Would also be interesting to follow magnetic field deflection idea
- Perhaps designs will be useful in SLAC, CEBAF, ILC…?

Acknowledgements

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