SAND2007-3760C

Magnetic Insulation

Precision Electron Flow Measurements in a Disk Transmission Line

Dissertation Proposal

Jeremy Martin

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Proposal Outline

- Research goals
- Theoretical background
- Hardware and diagnostics
- Particle-in-cell simulation

Research Goals

- Direct measurement of MITL electron flow in a radial disk geometry

- Comparison with standard measurement techniques

- Benchmarking of QUICKSILVER simulation software

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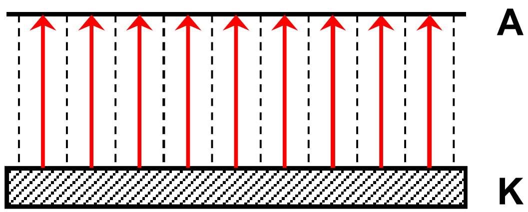
Theory of Self-Magnetic Insulation

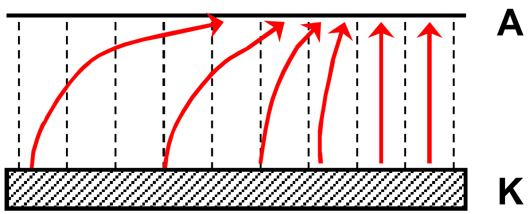
- Evolution of self-magnetic insulation
- Single particle analysis
- Analytical model
- Precision electron flow measurements

Self-Magnetic Insulation



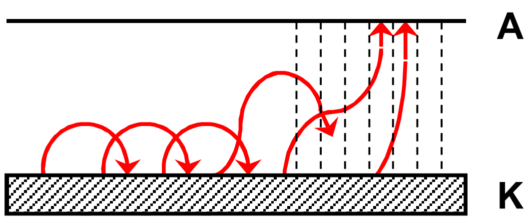
(a)

As the amplitude of the pulse rises appreciably, the cathode will begin to freely emit electrons. This conducting channel is known as the "loss front".



(b)

Current drawn by the MITL increases as electrons are conducted through the loss front. When large enough, the **B**-field will start to deflect electrons away from the anode and toward the direction of power flow.



(c)

As more loss current is conducted across the gap, larger sections of the line become insulated and the impedance of the line decreases until it reaches its self-limiting value.

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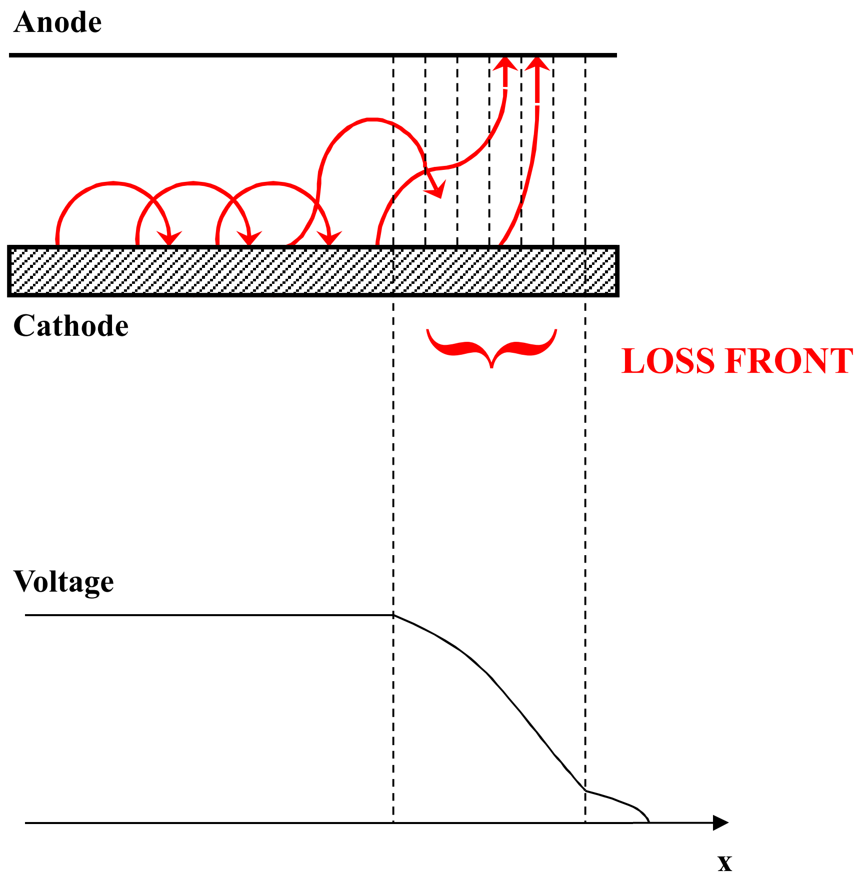
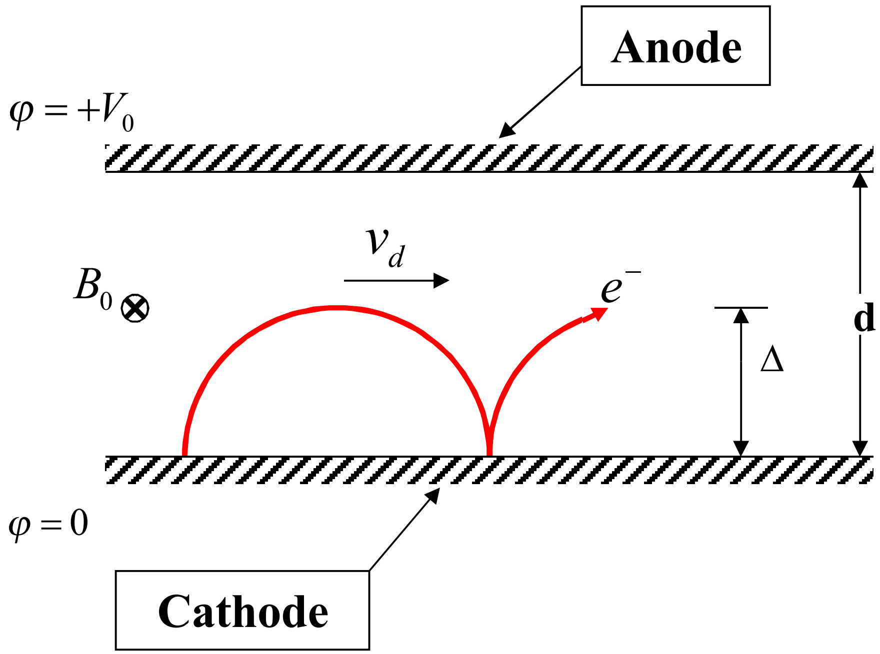
Pulse Broadening



Single Particle Dynamics*

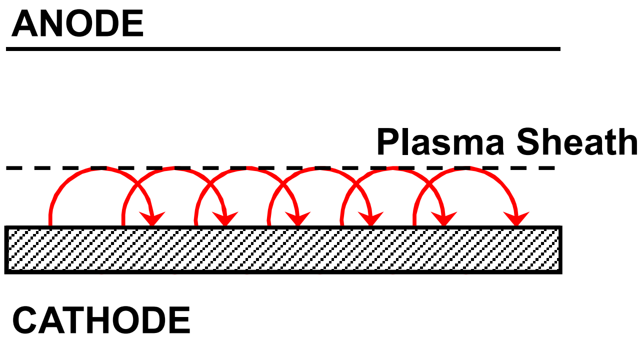


$$\frac{d}{dt}(\gamma m_e \vec{v}) = -e(\vec{E} + \vec{v} \times \vec{B})$$

Electron drift: $\vec{v}_d = \dfrac{\vec{E} \times \vec{B}}{B^2}$

*** Stationary Frame of Reference**

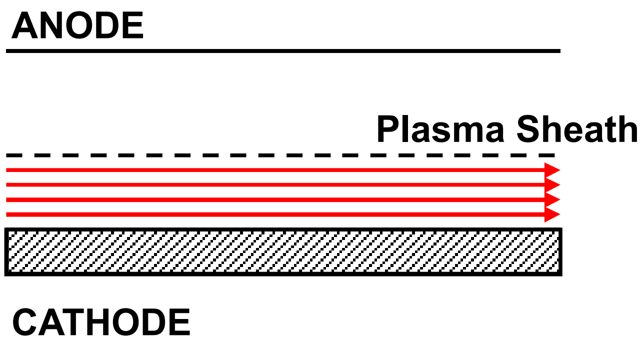
Analytical Models



Quasi-laminar Flow

$$\gamma = 1 + \frac{eV_0}{m_e c^2}$$

$$\vec{v} = \frac{e\vec{A}}{m_e \gamma}$$



Parapotential Flow

$$\vec{E} = -\vec{v} \times \vec{B}$$

Pressure Balance Theory*

- Magnetically insulated lines are efficient

- Cathode is a space-charge-limited electron emitter

*Mendel, Jr., Seidel, Rosenthal ('83)
Miller & Mendel, Jr. ('87)

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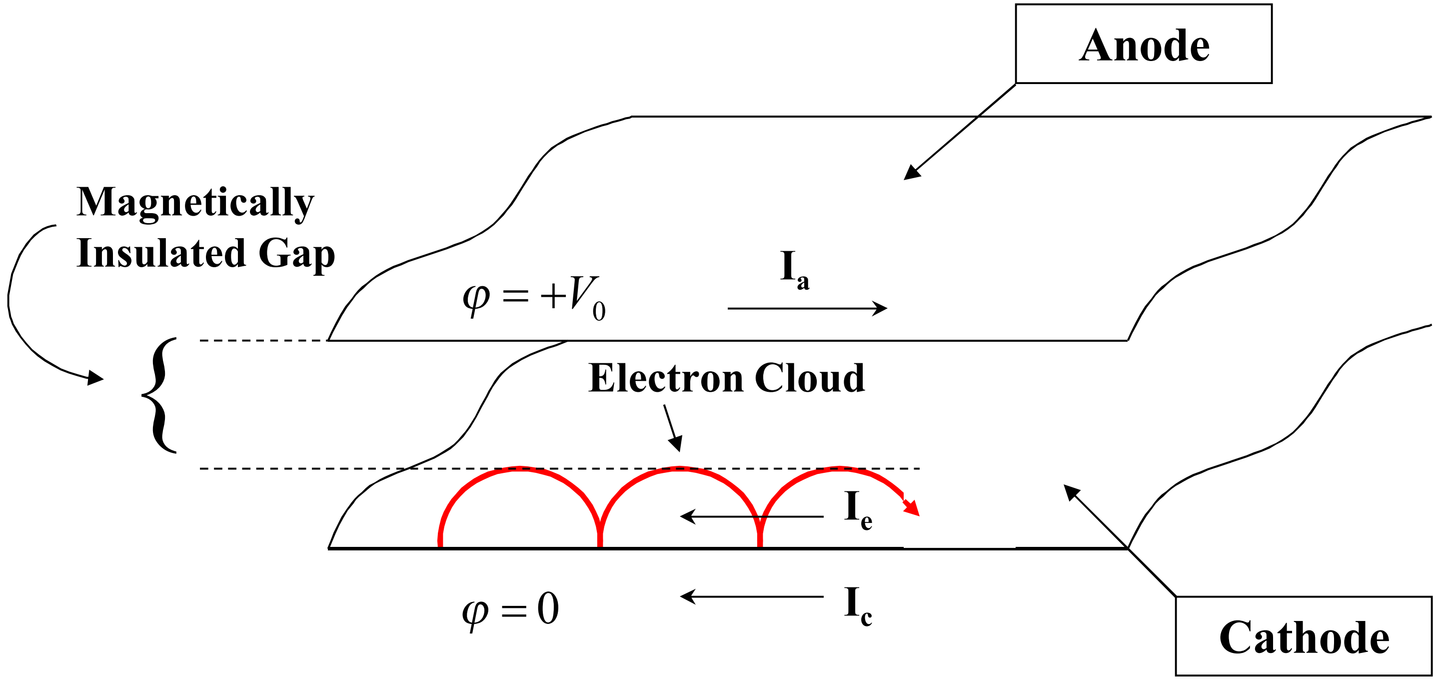
Parallel Plate MITL



$$I_a = I_e + I_c$$

Pressure Balance Theory

$$\frac{B_a^2}{2\mu_o} - \frac{\varepsilon_o E_a^2}{2} = \frac{B_c^2}{2\mu_o}$$

where $E_c = 0$ ➡ $E_a g = Z_0 \sqrt{I_a^2 - I_c^2}$

Pressure Balance Theory

$$V = Z_0 \sqrt{I_a^2 - I_c^2} - \frac{m_e c^2}{2e}\left(\frac{I_a^2}{I_c^2} - 1\right)$$

Potential across entire gap ***space charge correction***

$$V_s = \frac{m_e c^2}{2e}\left(\frac{I_a^2}{I_c^2} - 1\right) \quad \Rightarrow \quad \rho_c \geq \frac{e\varepsilon_o B_c^2}{m_e}$$

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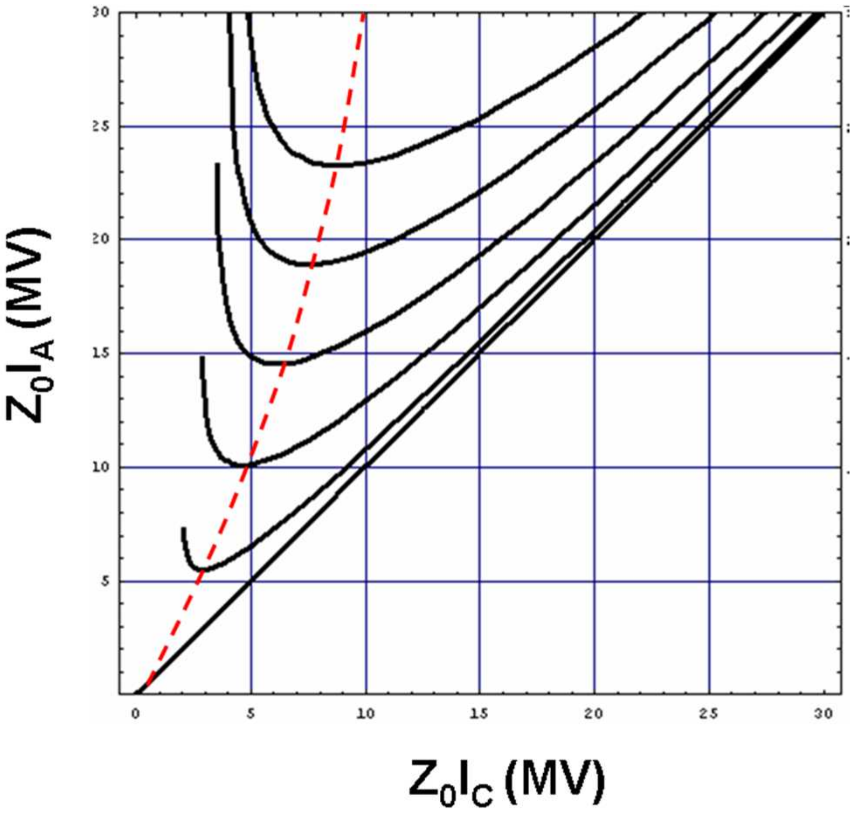
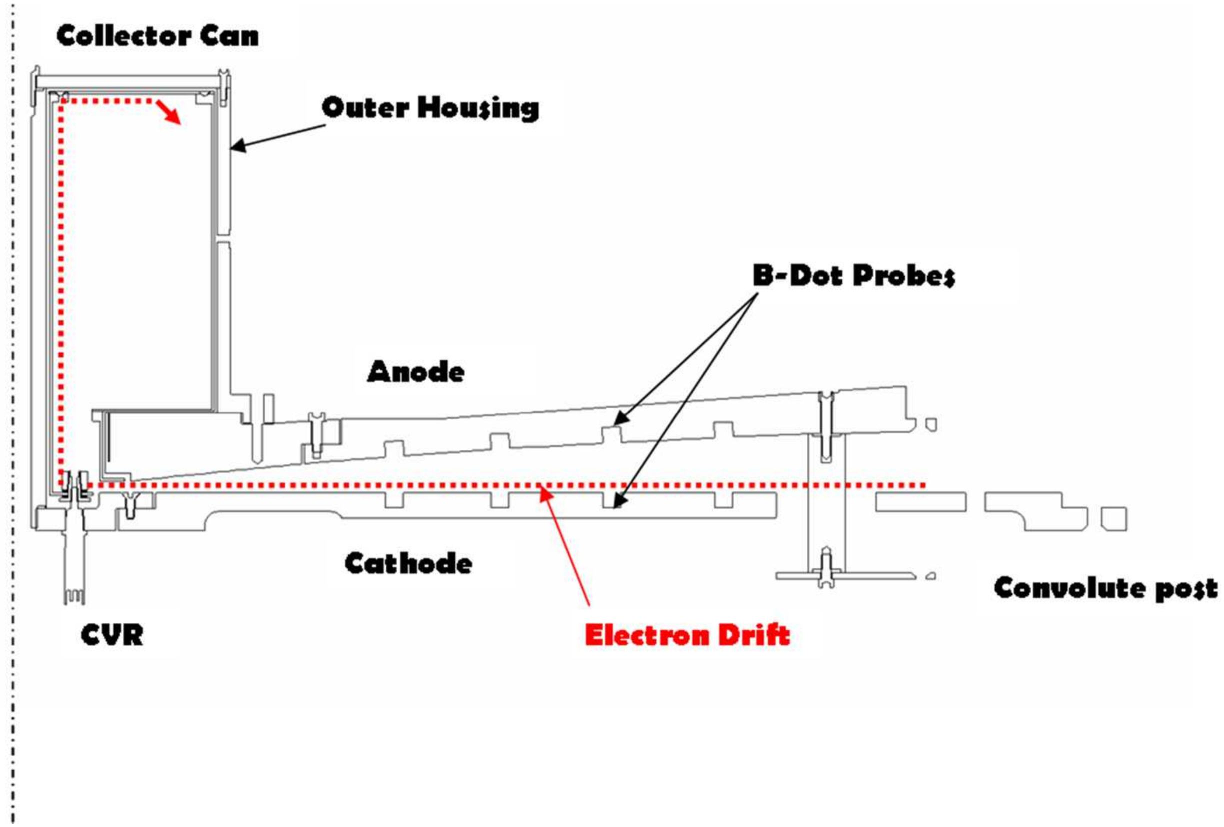
Voltage Contours



MITL Hardware

- Radial disk geometry
- Gap spacing varies with radius
- Flat cathode
- Electron collector can

Cross-Sectional Geometry



Inductance Calculations

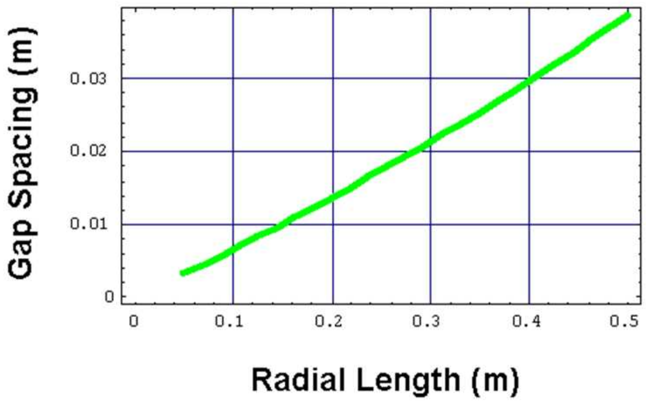
Fractional change in radial electron flow:

$$\beta = \frac{1}{I_e}\frac{\partial I_e}{\partial r} = 2\frac{\dot{L}^2 - \ddot{L}L}{L\dot{L}}$$

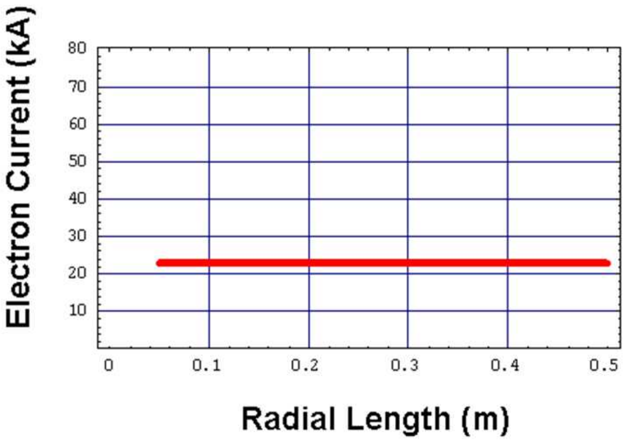
Inductance profile:

$$L(r) = C_2 \exp\left[-\frac{2C_1}{\beta}\exp\left[-\frac{\beta}{2}(r - r_o)\right]\right]$$

Constant Electron Flow



(a)



(b)

$$g_{const}(r) = \frac{g_o r}{r_o}\exp\left[\frac{60 g_o \left(r - r_o\right)}{L_o r_o c}\right]$$

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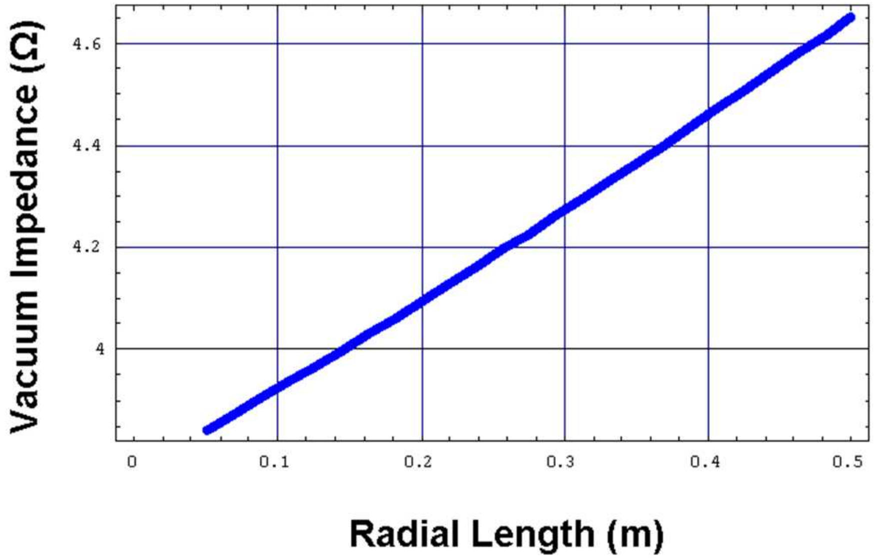
Constant Electron Flow



$$Z(r) = \frac{60 g_o}{r_o} \exp\left[\frac{60 g_o (r - r_o)}{L_o r_o c}\right]$$

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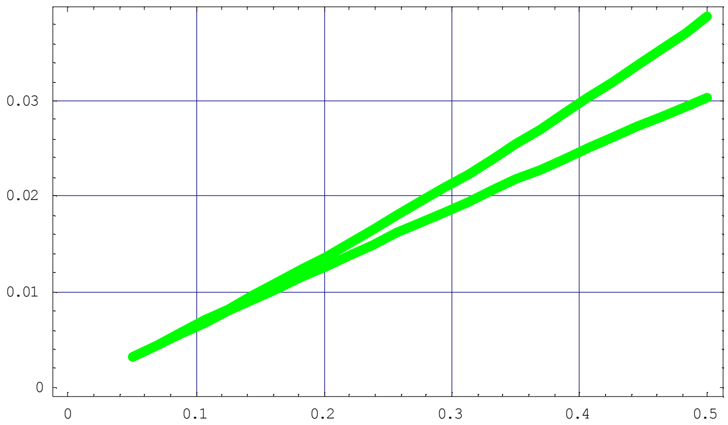
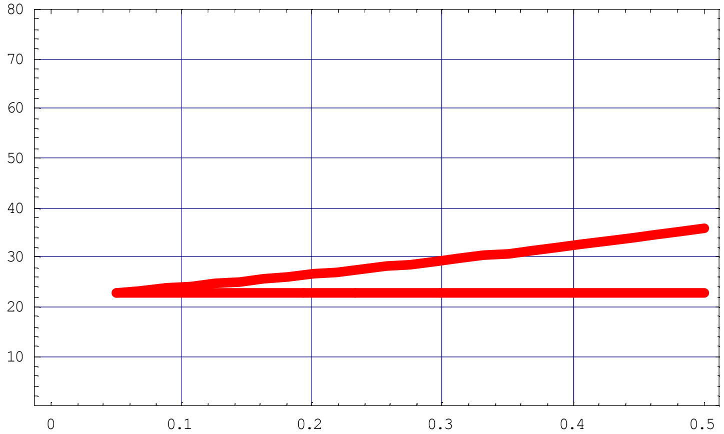
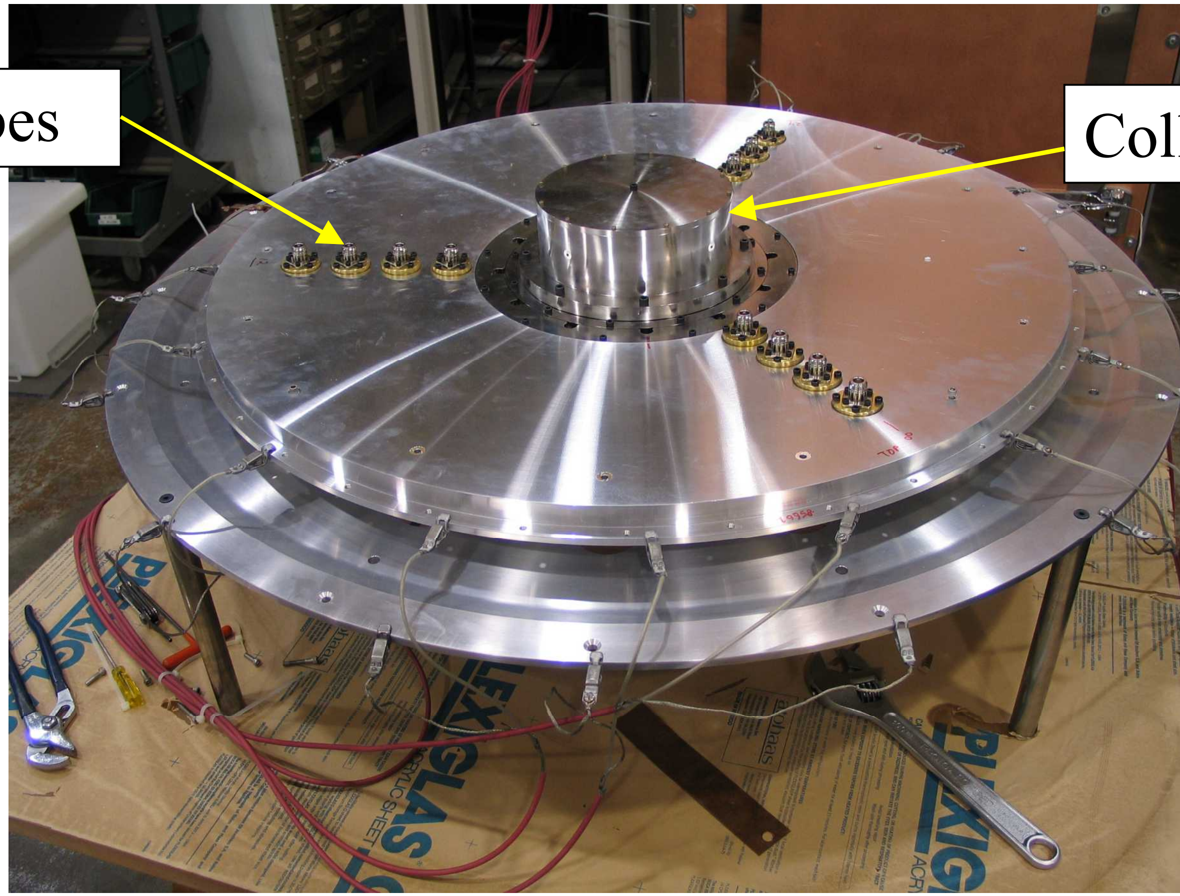
Reducing Electron Flow



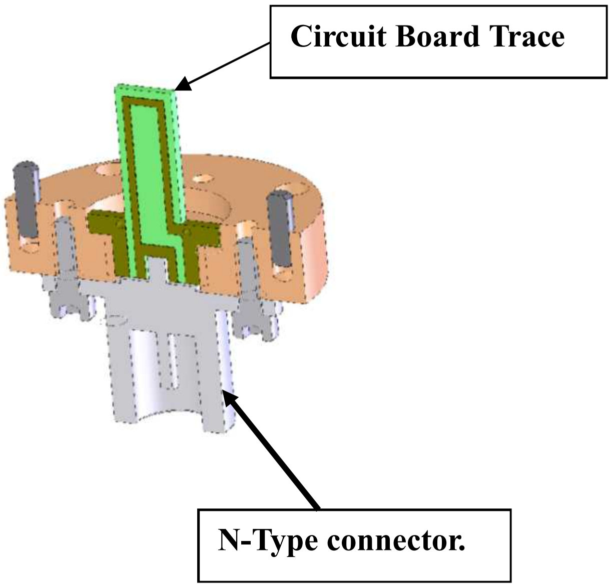


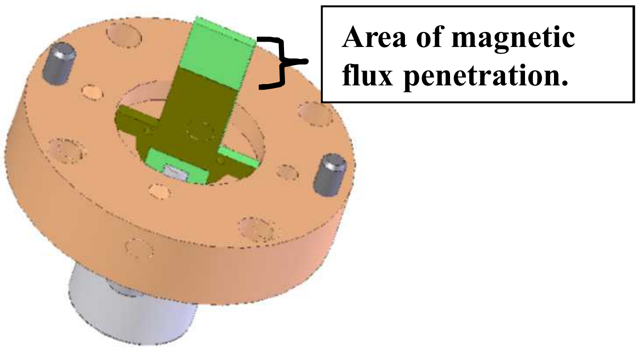
$$g_{reducing}(r) = \frac{g_o r}{r_o} \exp\left[\frac{120 g_o}{c L_o r_o} - \frac{120 g_o}{c L_o r_o} \exp\left[-\frac{1}{2}(r - r_o) \right] - \frac{1}{2}(r - r_o) \right]$$

MITL Hardware

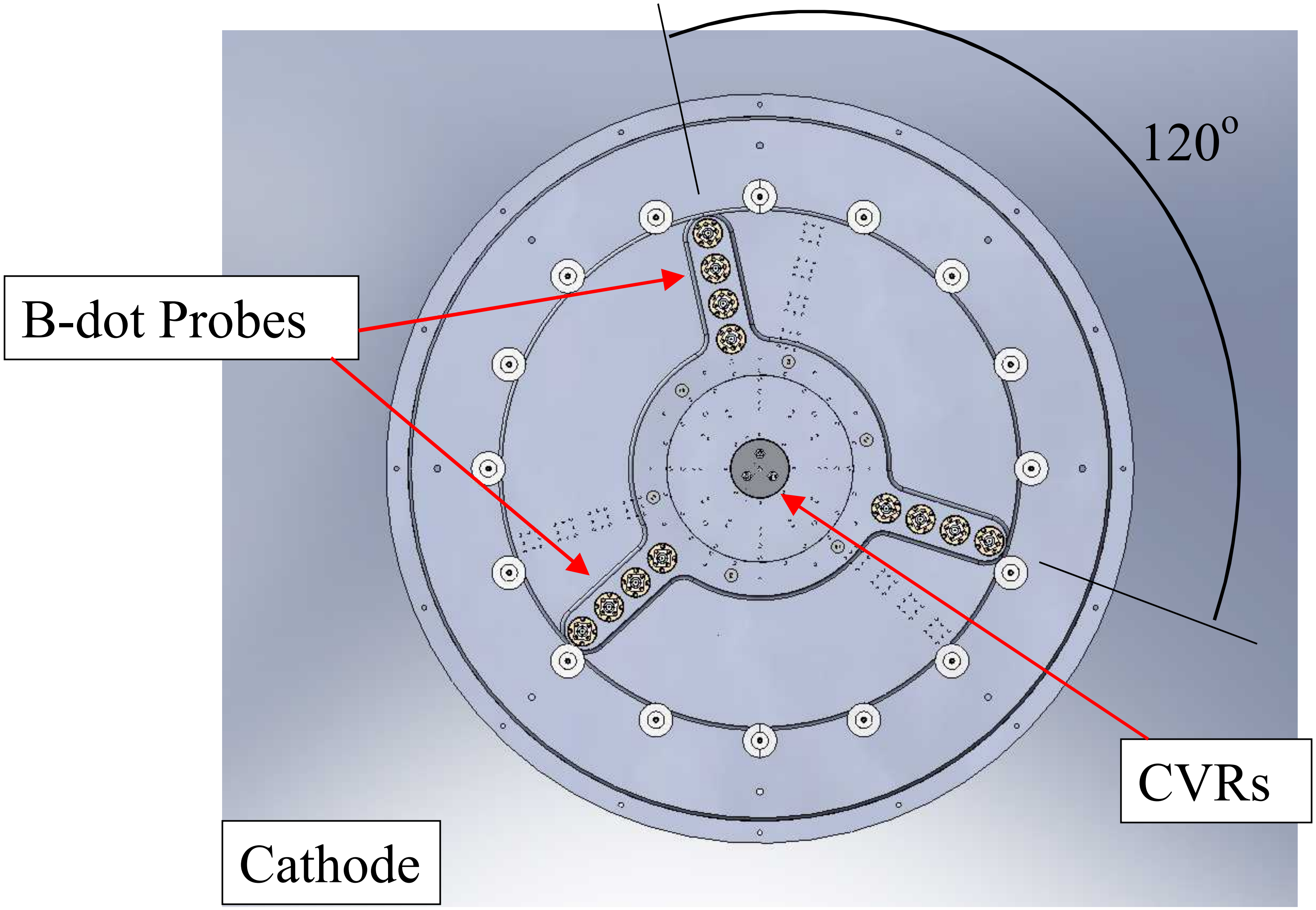


Diagnostics

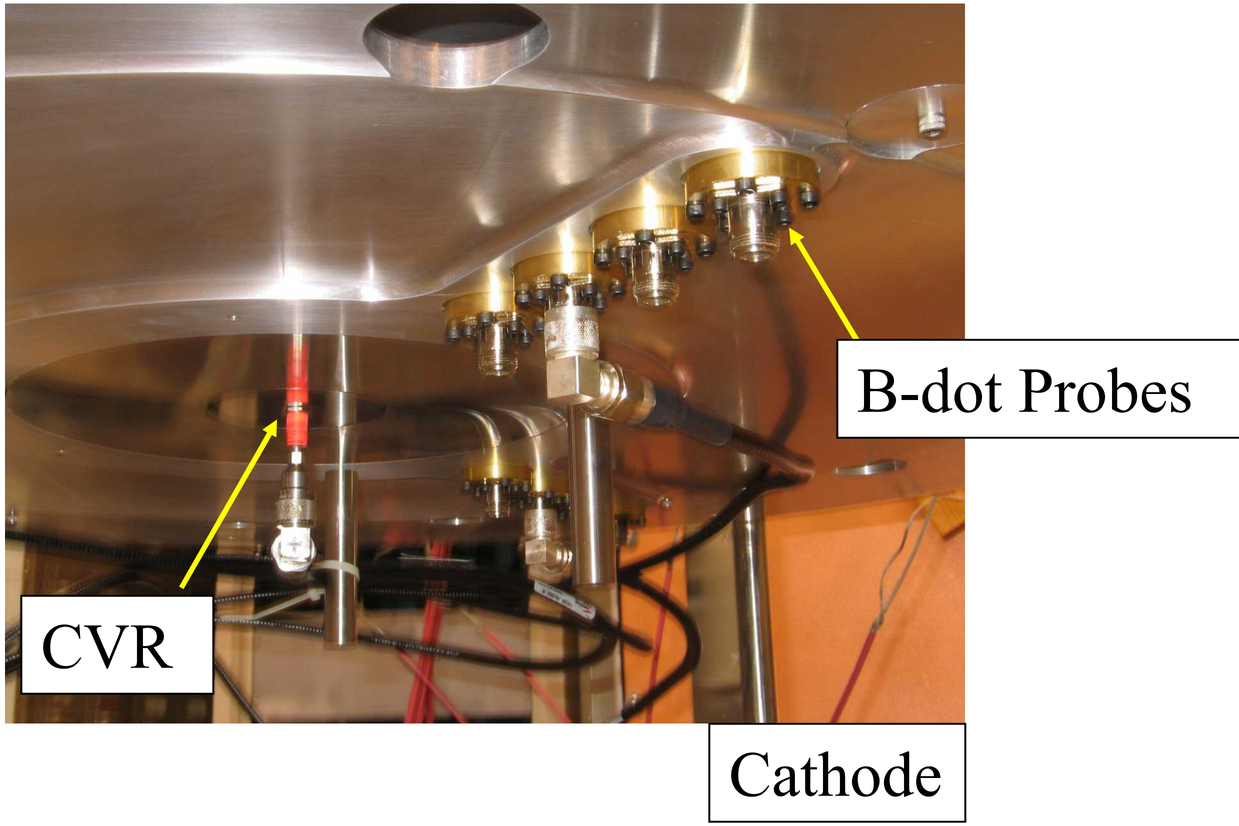




Diagnostic Layout



MITL Hardware



Shielded Enclosure

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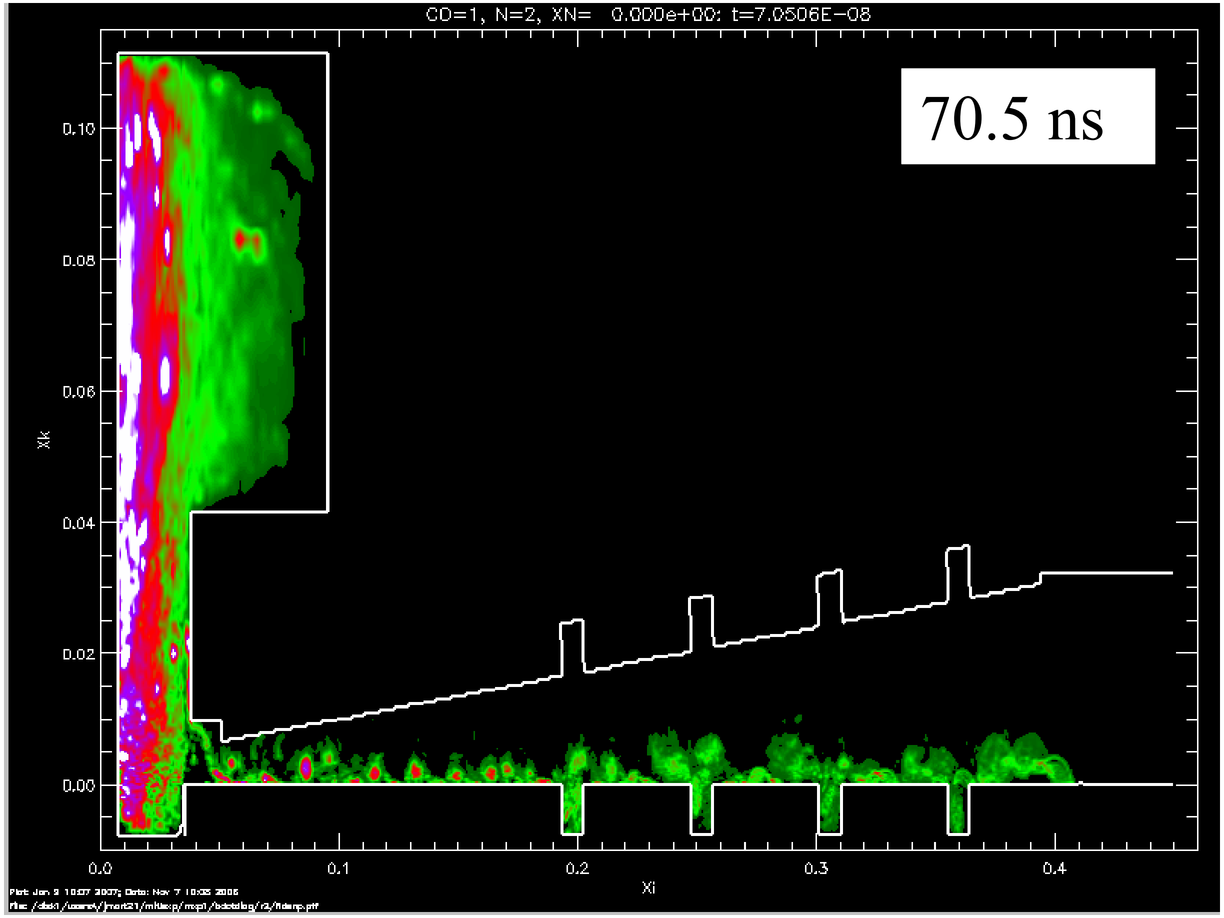
QUICKSILVER

- FDTD, 3-D, electromagnetic PIC code
- Parallel processing
- Numerous diagnostics

Electron Density



Recap

- Provide method of direct measurement of the electron flow into the MITL load

- Benchmarking for Sandia National Laboratories' QUICKSILVER program suite

- Pin-point additional locations of electron loss in the line

References

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3. C. W. Mendel, Jr., and S. E. Rosenthal, Phys. Plasmas 3, 4207 (1996)
4. C. W. Mendel, Jr., and D. B. Seidel, Phys. Plasmas 6, 4791 (1999)
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6. P. A. Miller and C. W. Mendel, Jr., J. Appl. Phys. 61, 529 (1987)

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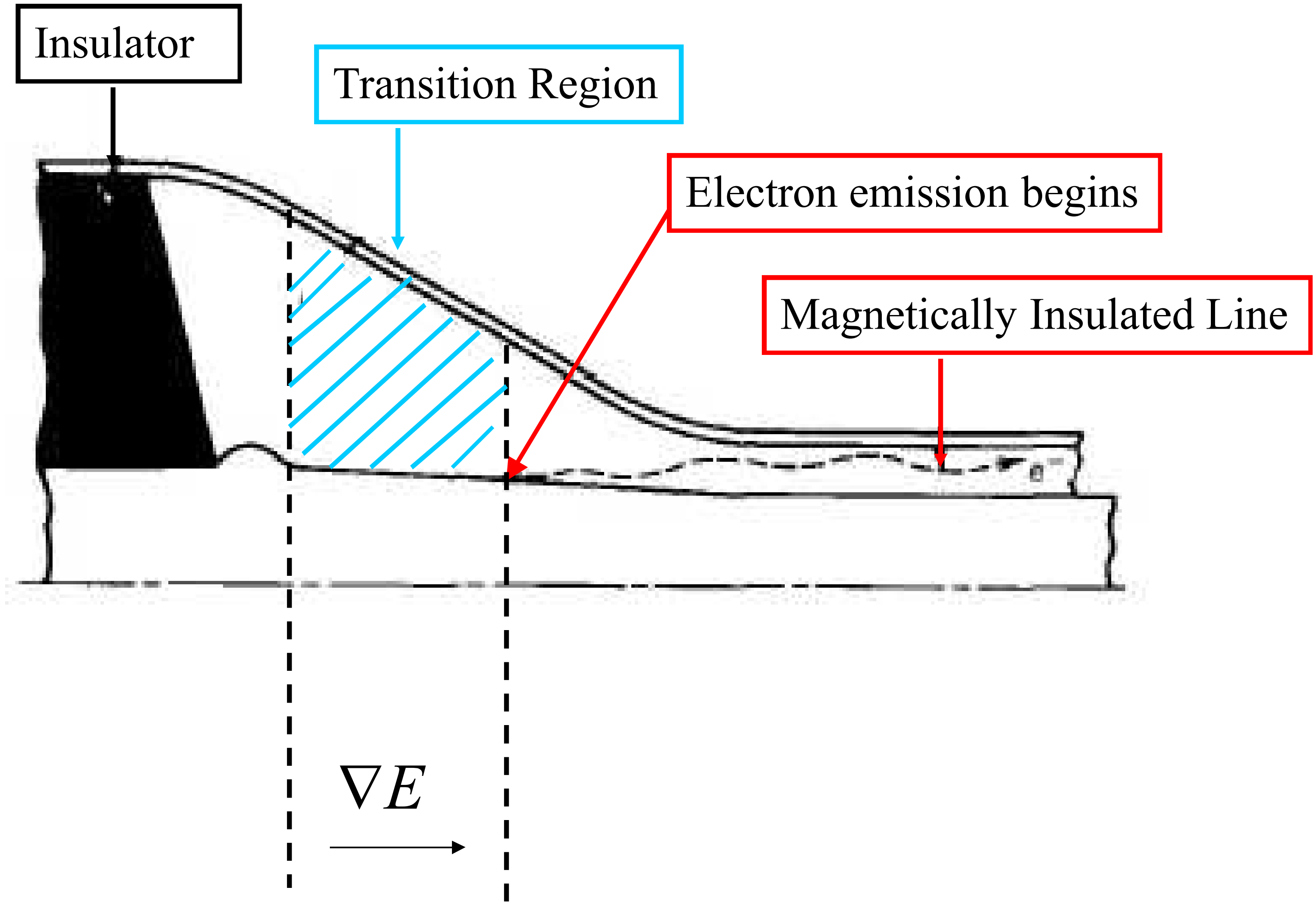
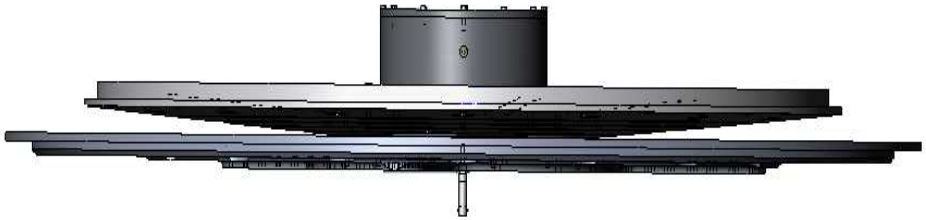
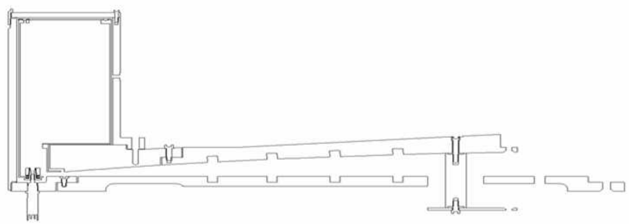
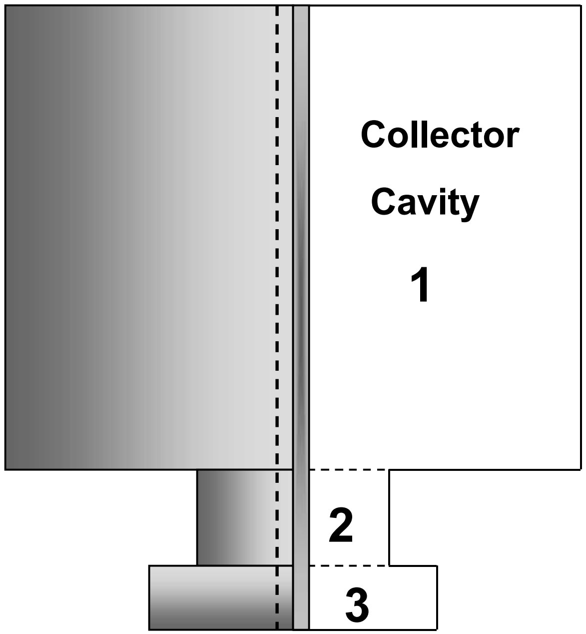
Vacuum Interface Region

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Cavity
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