Thermionic Sources for Electron Cooling

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05/01/24

Outline

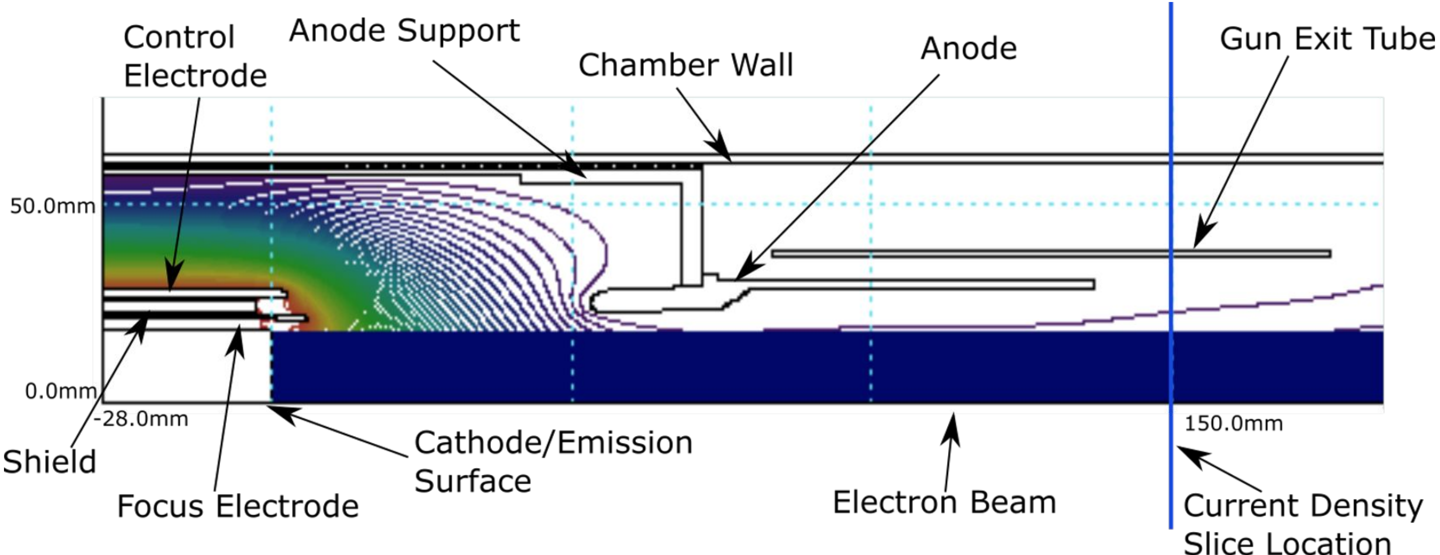
- Goals for Strong and Weak sources
- Strong and Weak source requirements
- Strong Source Design
- Explorations for Weak Source Design
- Weak Source Design Options

Goals

- Design two thermionic electron sources in the IOTA ring:
    - Strong Source: Explore dynamics due to space-charge with large transverse tune shifts. The space-charge forces create fast emittance growth and beam-loss within the first couple of hundred turns. Therefore we require a strong electron source to counter these effects.
    - Weak Source: At beam currents much smaller than the maximum, IBS is the main source of emittance growth and limits the beam lifetime in this regime, constraining other experiments at IOTA. A weak electron source will compensate for heating, which will be useful for all research with proton beams in the IOTA ring.

General Source Features:

- Both electron sources will operate in a highly magnetized environment, with a solenoidal magnetic field within 0.1 - 0.3 T.
- The sources will both operate at a kinetic energy of -1.36 keV.



Strong Source Requirements

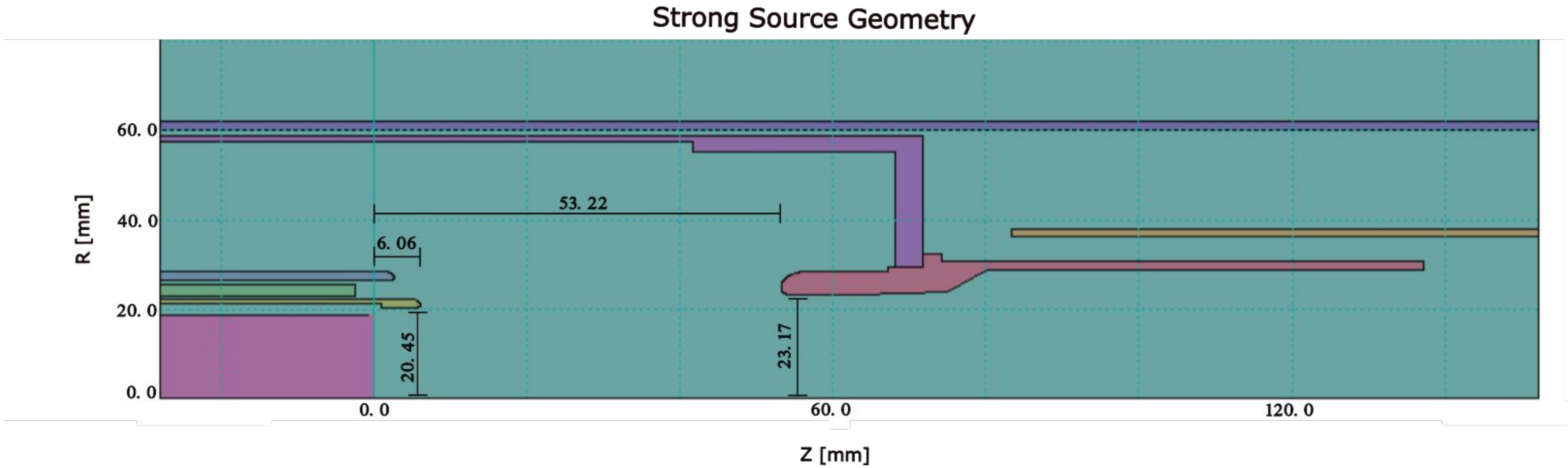
Strong Electron source:

Operating Voltage	1.36 kV
B field	0.1 T
Current	~80 mA
Radius of flat current density distribution	~12 mm
Current density	78.6 A/m^2

- The magnetic field strength at the source and cooling section is the same for the strong source.

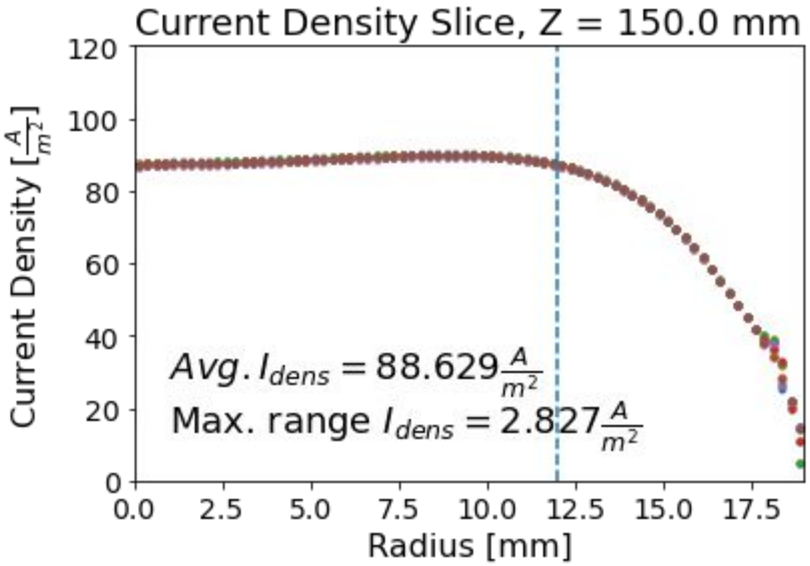
Strong Source Design:

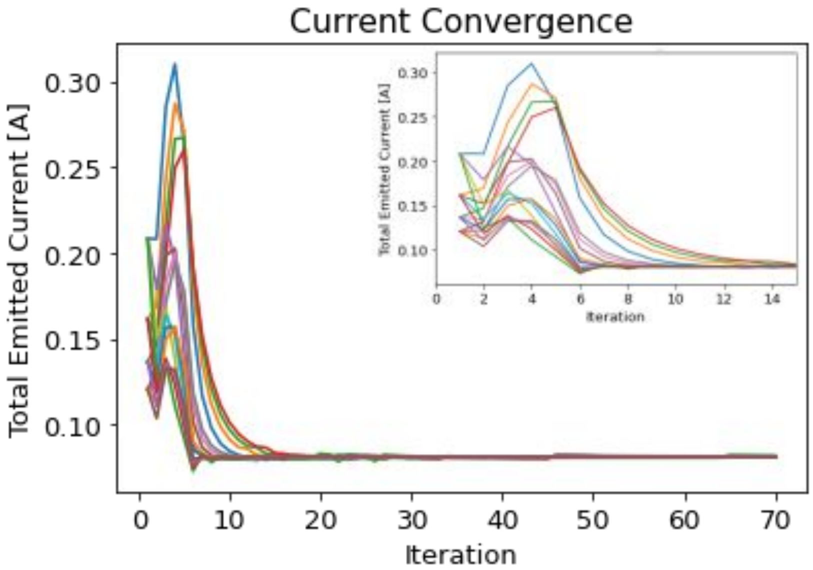
Strong Source Design Geometry:



Strong Source emission and convergence:

Final current: I = 0.0811 ± 0.0003 A

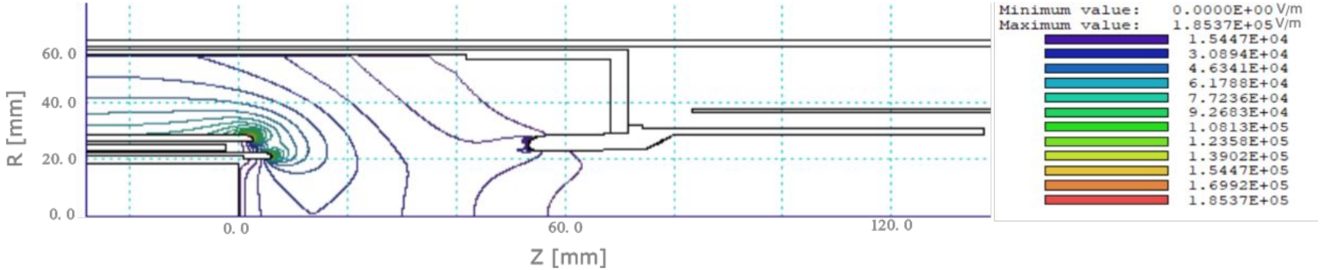




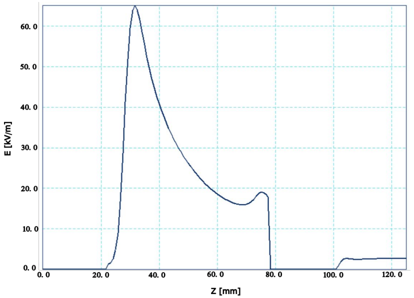
Strong Source Electric Field:

Electric Field Profile:

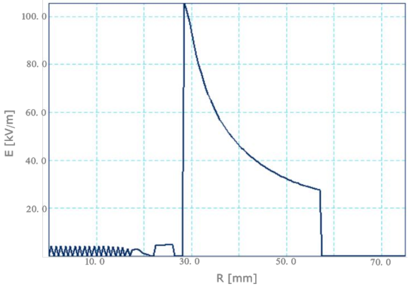
- 99th percentile max. electric field: 99.096 kV/m
    - Order of magnitude smaller than the threshold for arcing



The electric field magnitude along Z at R = 25 mm



The electric field magnitude at the Z = 0 mm slice



Weak Source Requirements

Weak electron source:

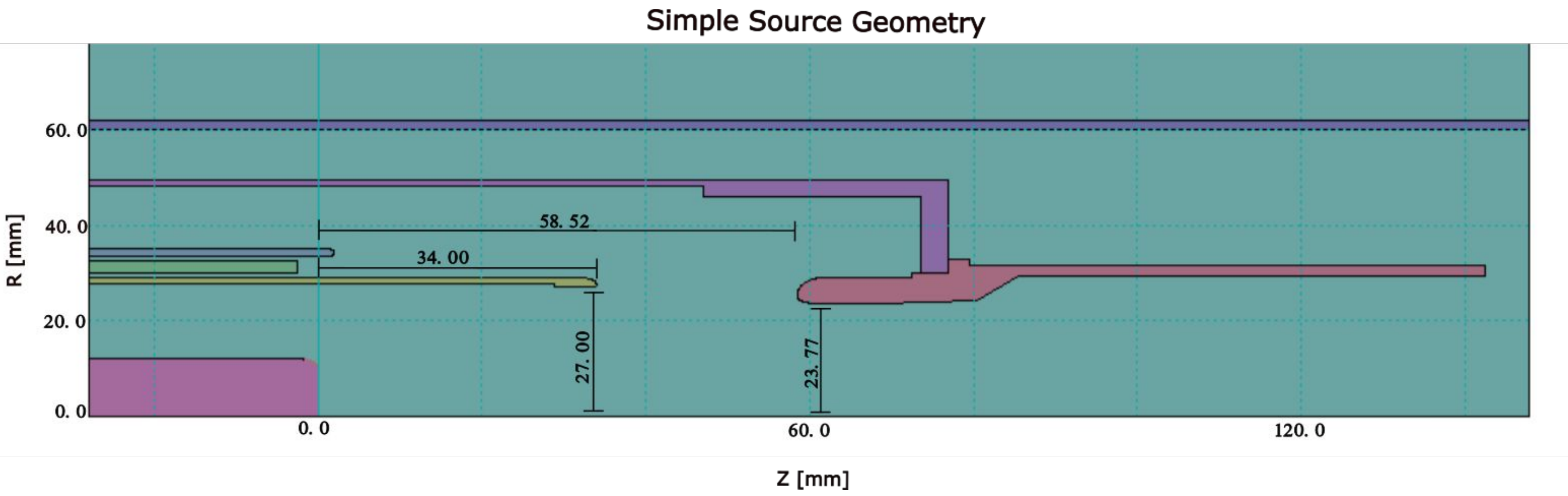
Operating Voltage	1.36 kV
B field	0.3 T
Current	1-5 mA
Radius of flat current density distribution	10 - 20 mm
Current density	0.796 - 15.915A/m^2

- The electron beam in the source will start at a smaller radius and will expand to match these parameters by magnetic field expansion before co-propagating with the protons.

Past Weak Source Design

Past Weak Source Design Geometry:

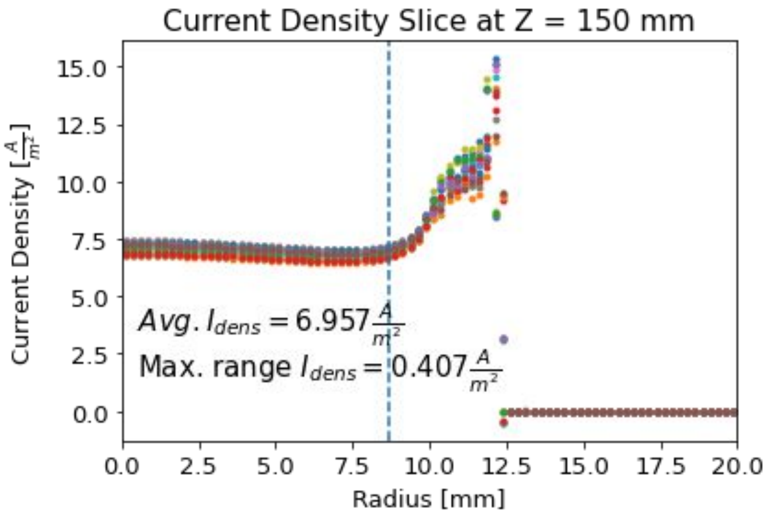
- Anode at ground, focus electrode at -1.36keV

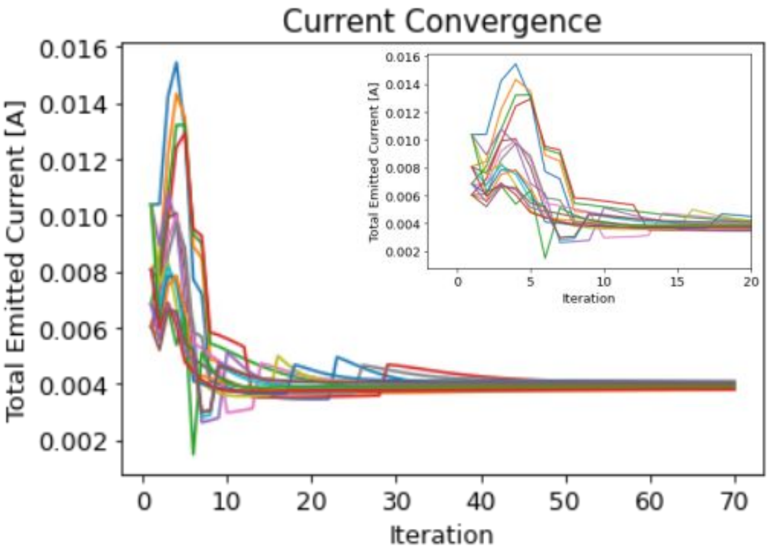


Past Weak Source Design

Final total current emitted is I= 0.0039 ± 0.0001 A

The magnetic field of the solenoid to expand the beam will be 0.1T. This will expand the beam a radius of 15 mm. At this radius, the beam's current density will be approximately 2.31 A/m^2.

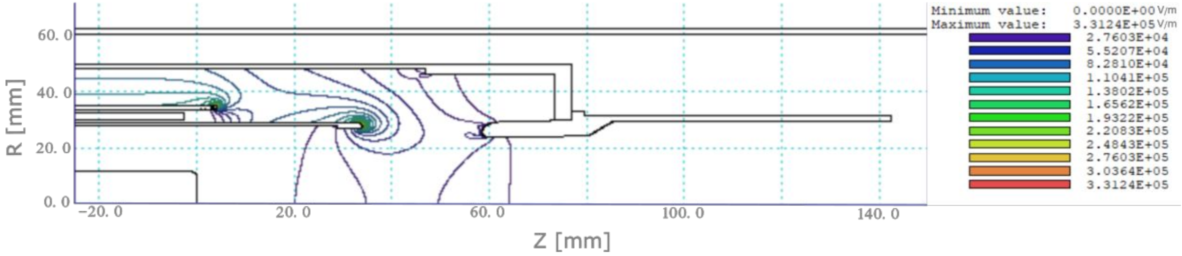




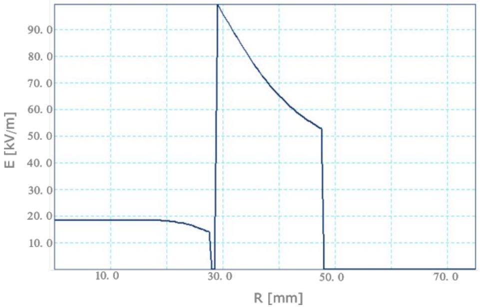
Past Weak Source Design

Electric Field Profile:

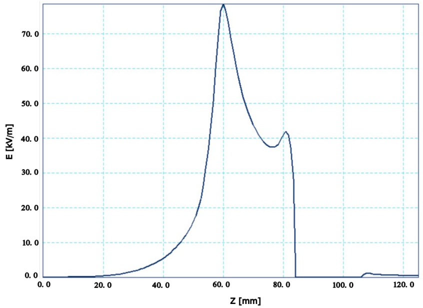
- 99th percentile max. electric field: 133.27 kV/m
    - Order of magnitude smaller than the threshold for arcing



The electric field magnitude at the Z = 25 mm slice



The electric field magnitude along Z at R = 25 mm



Weak Source Design: Additional Parameters

- Encountered difficulties with getting the focus electrode closer to the cathode while keeping the emission flat and with the small current density
- Additional Parameters to change for this:
  - Change focus electrode potential - make more negative than cathode: reduce emission
  - Change anode potential - make more negative than ground: reduce emission
- Performed sweeps for each parameter to visualize how everything changes.

Focus Electrode X position variation:

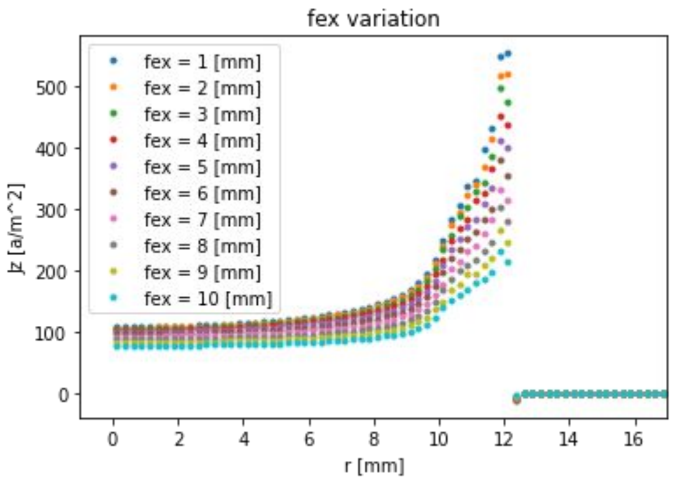
Fe_y = 27 mm

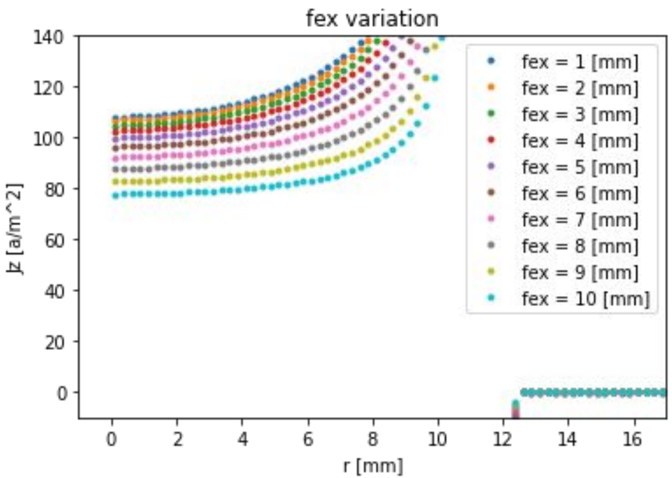
Focus electrode potential = -1370 kV

Anode_x = 77 mm

Anode_y = 30 mm

Anode potential = ground





Focus Electrode potential variation:

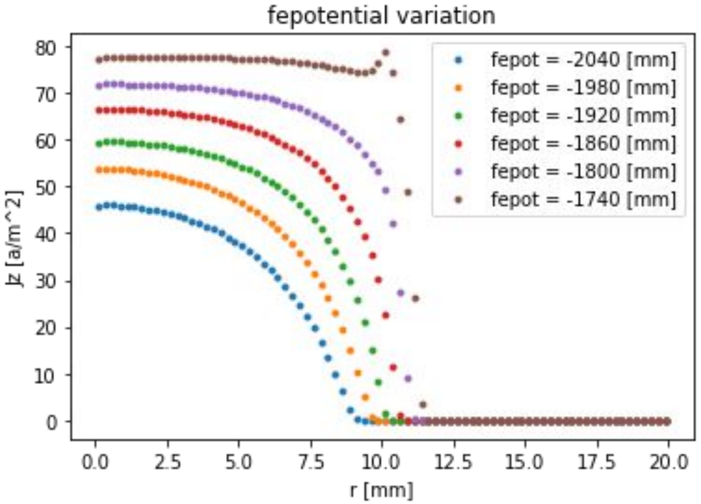
Fe_x = 4 mm

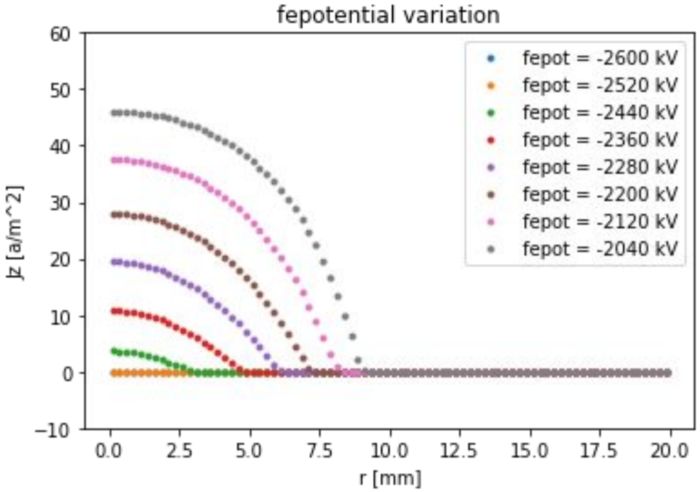
Fe_y = 27 mm

An_x = 77 mm

An_y = 30 mm

An_pot = 0 kV





Anode Y position variation:

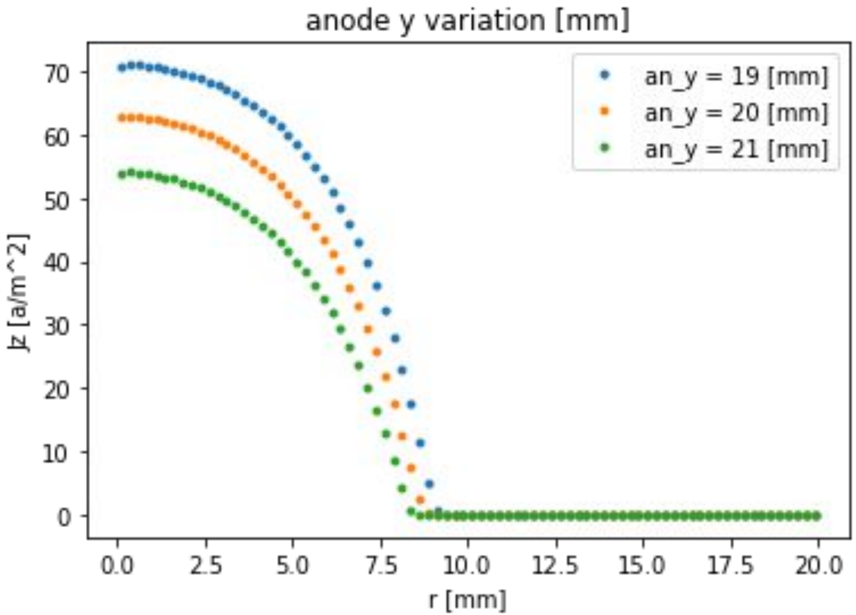
Fe_x = 4 mm

Fe_y = 27 mm

Focus electrode potential = -2340 kV

Anode_x = 77 mm

Anode potential = ground



Fe y position variation:

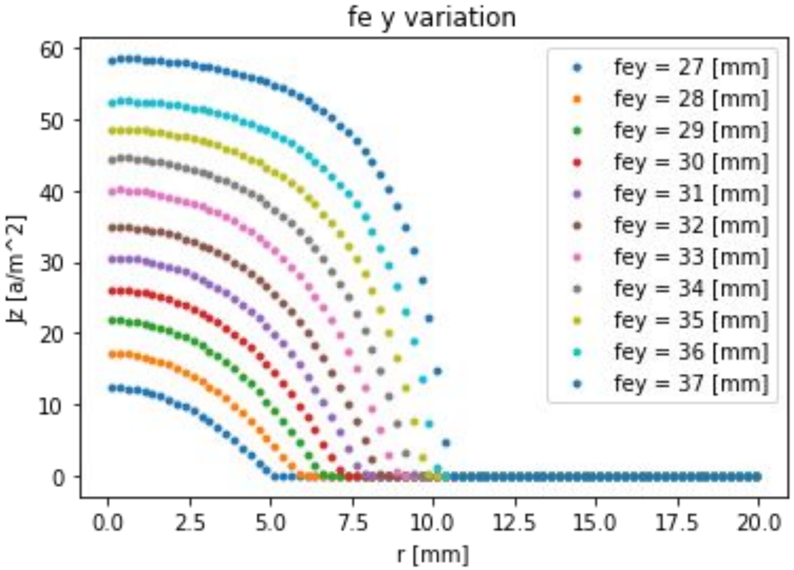
Fe_x = 4 mm

Focus electrode potential = -2340 kV

Anode_x = 77 mm

Anode_y = 30 mm

Anode potential = ground



Anode Potential Variation:

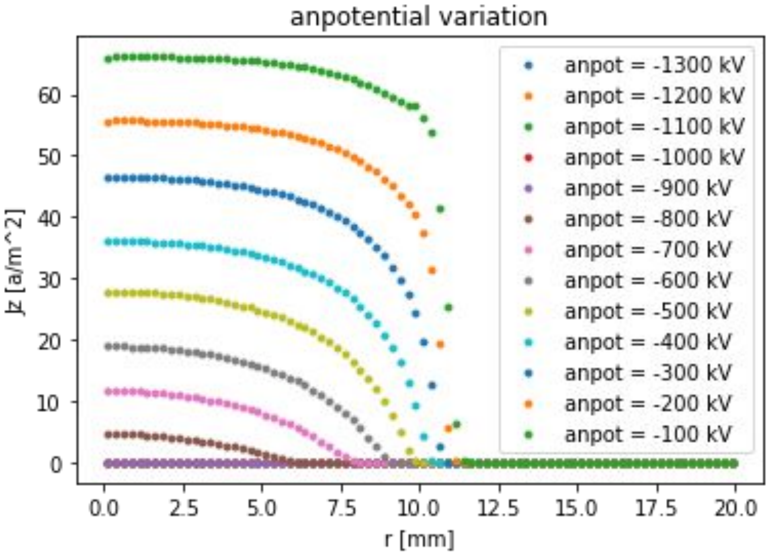
Fe_x = 4 mm

Fe_y = 27 mm

Focus electrode potential = -1740 kV

Anode_x = 77 mm

Anode_y = 30 mm



Anode X position variation:

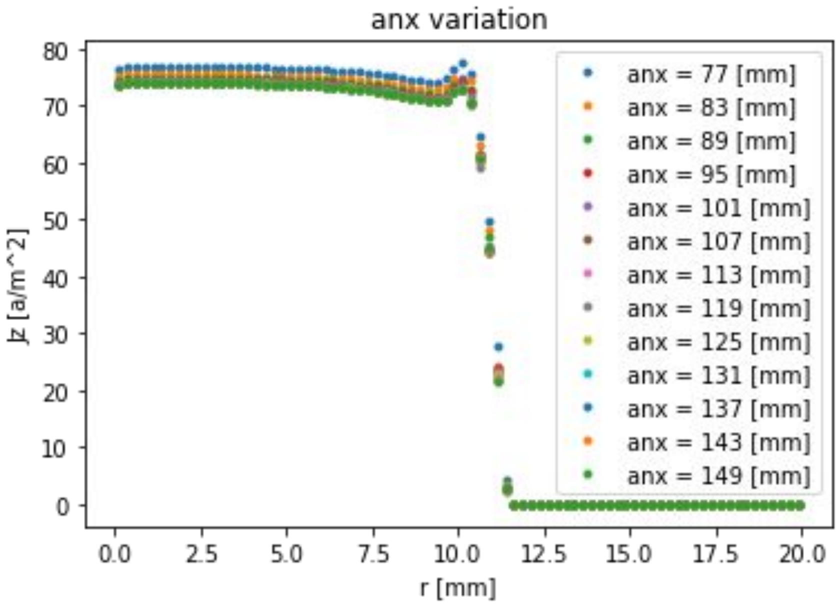
Fe_x = 4 mm

Fe_y = 27 mm

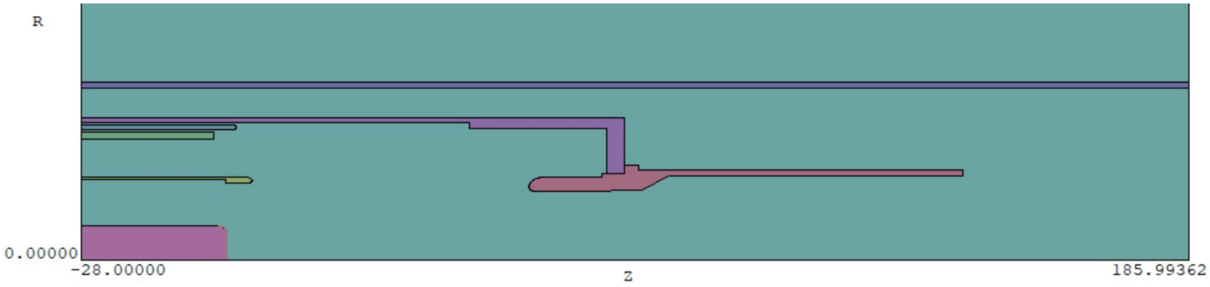
Focus electrode potential = -1740 kV

Anode_y = 30 mm

Anode potential = 0 kV



Weak Source Alternative Design Options:



Fex = 5 mm

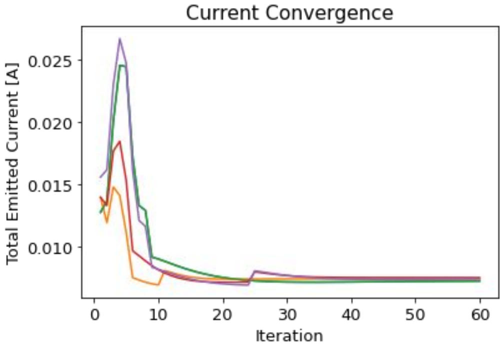
Fey = 27 mm

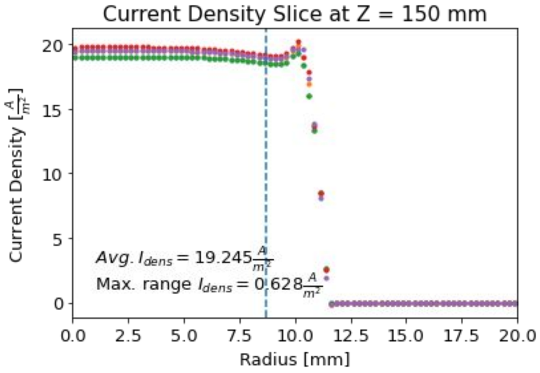
Anx = 58.5 mm

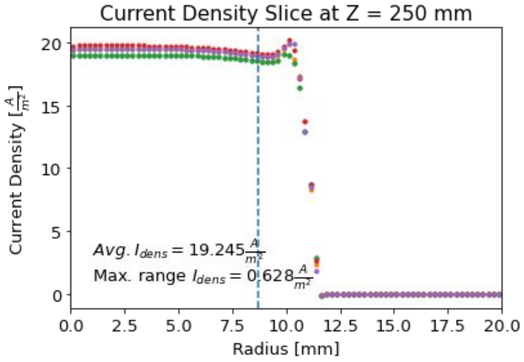
an y = 23.8 mm

Fe potential = -1500 kV

An potential = -800 kV



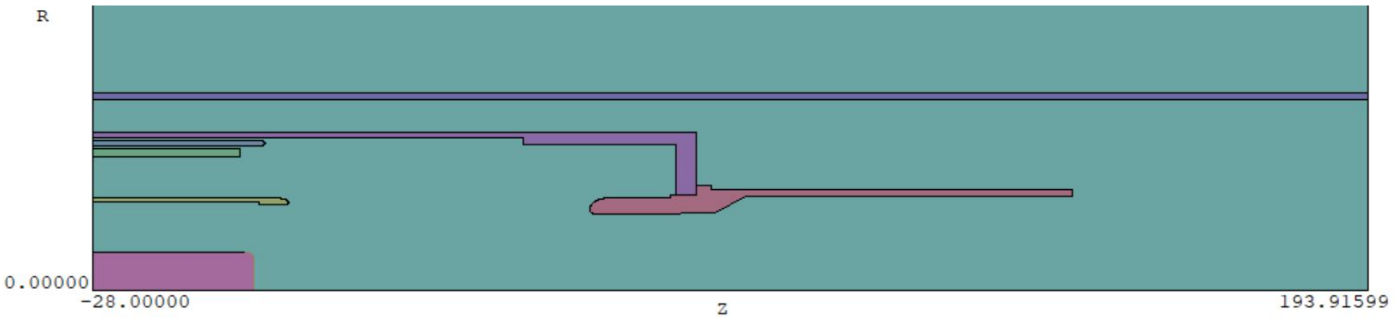




After expansion (flat region):
r = 15.06 mm
Jz = 6.422 A/m^2
I = 4.57mA

I = 0.0073 ± 0.0001 A

Weak Source Alternative Design Options:



Fex = 6 mm

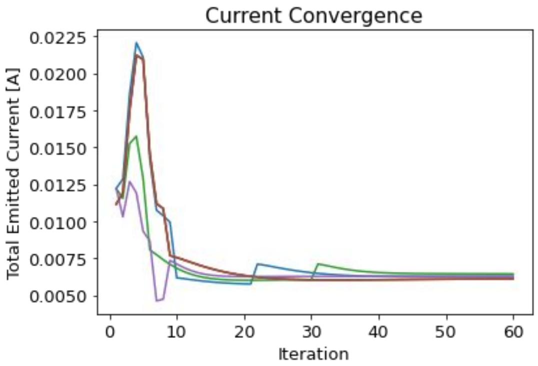
Fey = 27 mm

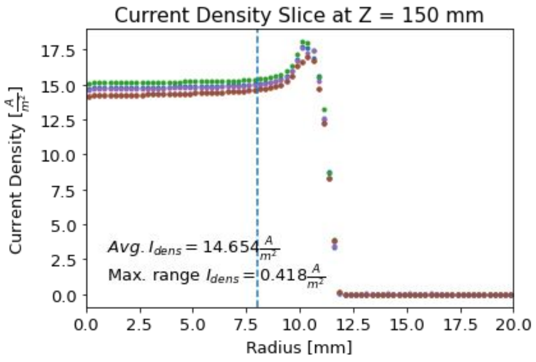
Anx = 58.5 mm

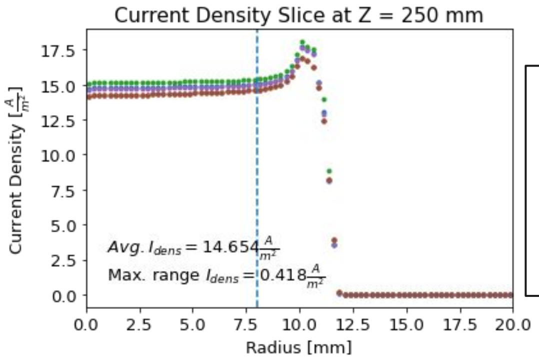
an y = 23.8 mm

Fe potential = -1450 kV

An potential = -900 kV



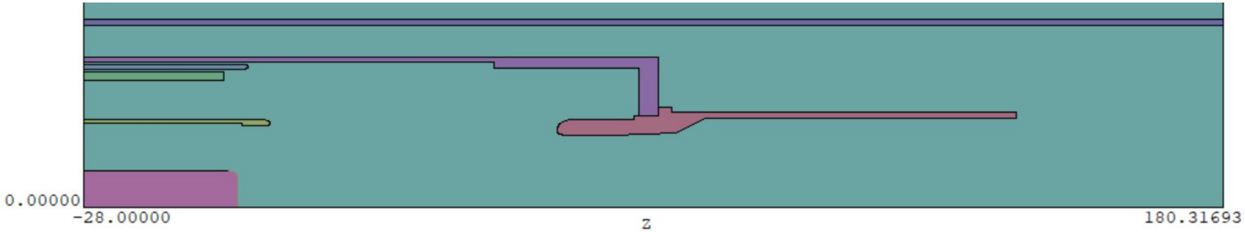




After expansion (flat region):
r = 13.856 mm
Jz = 4.88 A/m^2
I = 2.94 mA

I = 0.0062 ± 0.0001 A

Weak Source Alternative Design Options:



Fex = 6 mm

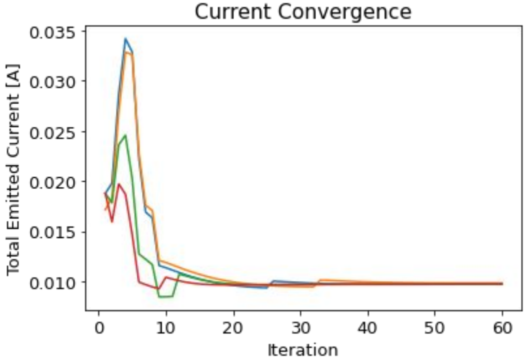
Fey = 27 mm

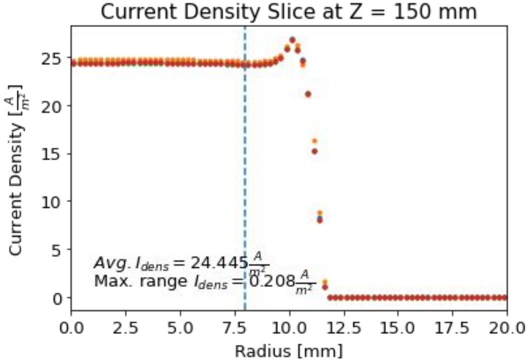
Anx = 58.5 mm

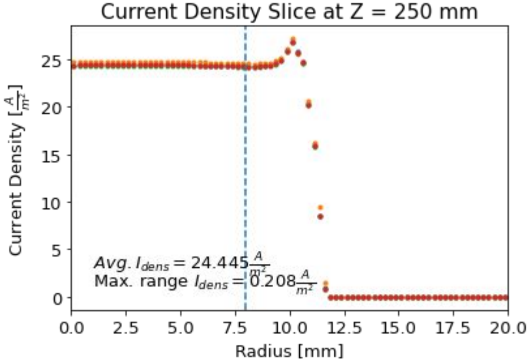
an y = 23.8 mm

Fe potential = -1500 kV

An potential = -700 kV



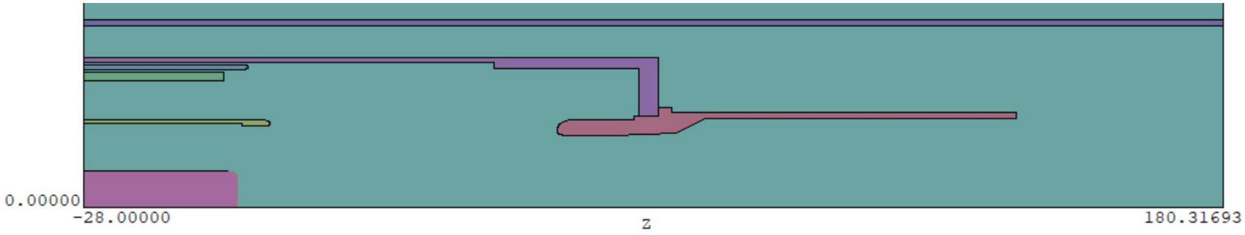




After expansion (flat region):
r = 13.856 mm
Jz = 8.15 A/m^2
I = 4.92 mA

I = 0.0097 ± 0.0000 A

Weak Source Alternative Design Options:



Fex = 6 mm

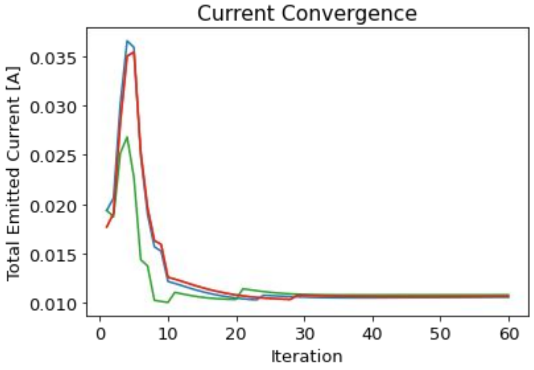
Fey = 27 mm

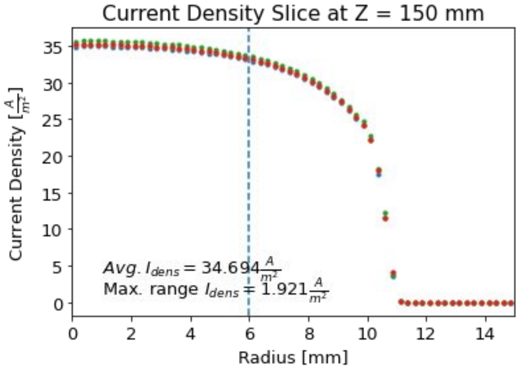
Anx = 58.5 mm

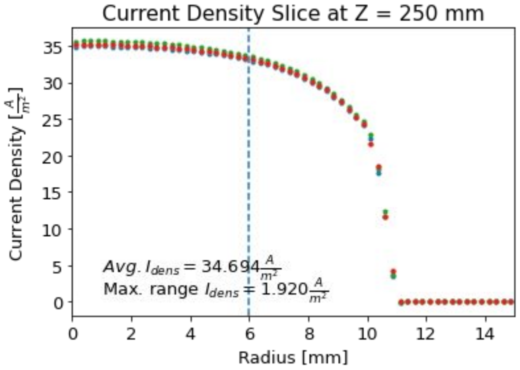
an y = 23.8 mm

Fe potential = -1610 kV

An potential = -450 kV



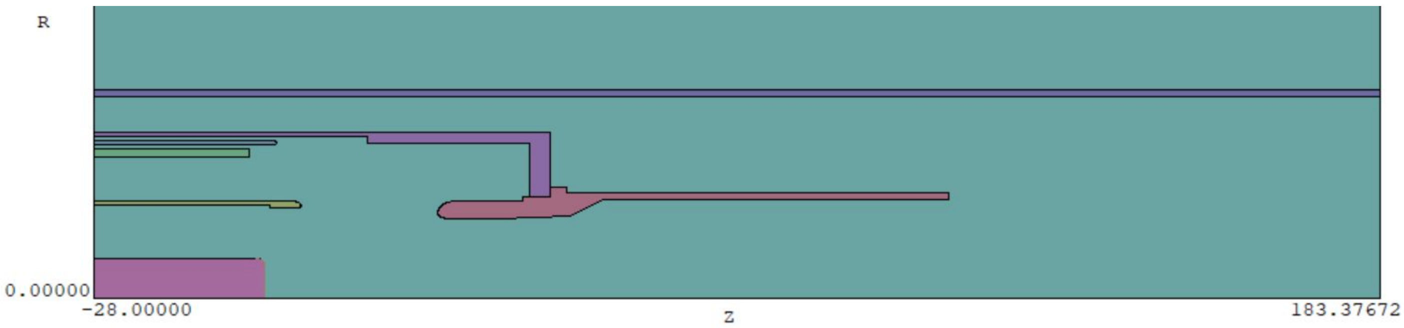




After expansion (flat region):
r = 10.39 mm
Jz = 11.57 A/m^2
I = 3.9 mA

I = 0.0107 ± 0.0001 A

Weak Source Alternative Design Options:



Fex = 6 mm

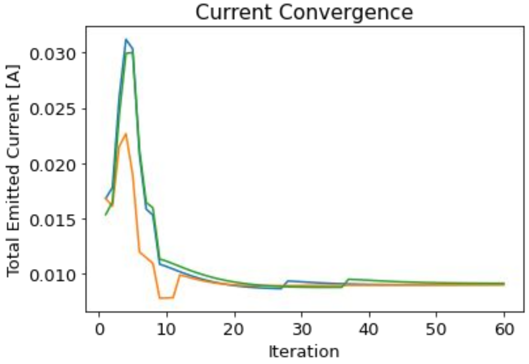
Fey = 27 mm

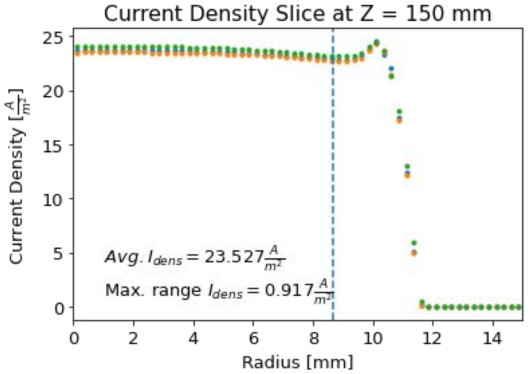
Anx = 28.5 mm

an y = 23.8 mm

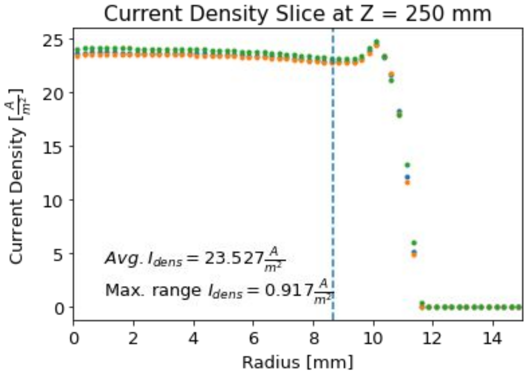
Fe potential = -1610 kV

An potential = -450 kV





I = 0.0091 ± 0.0001 A

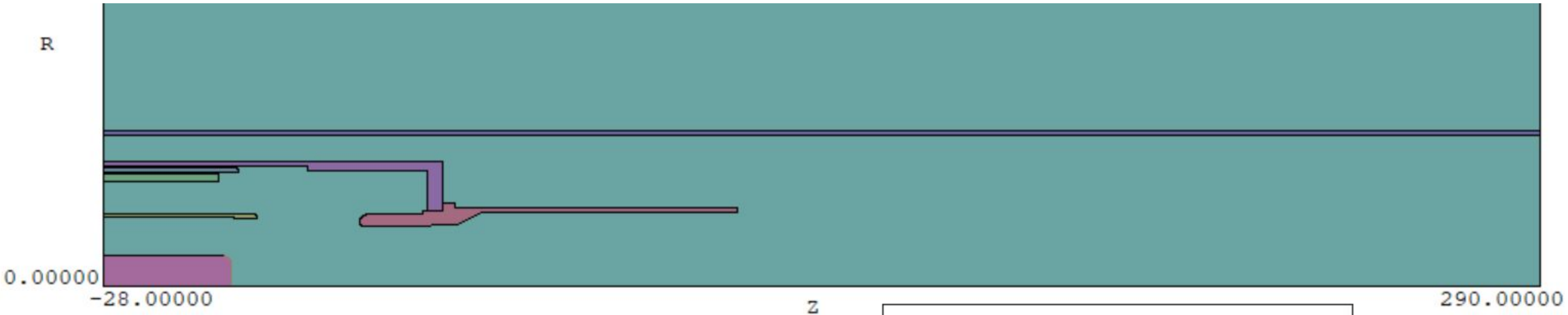


After expansion (flat region):
r = 15.06 mm
Jz = 7.85 A/m^2
I = 5.6 mA

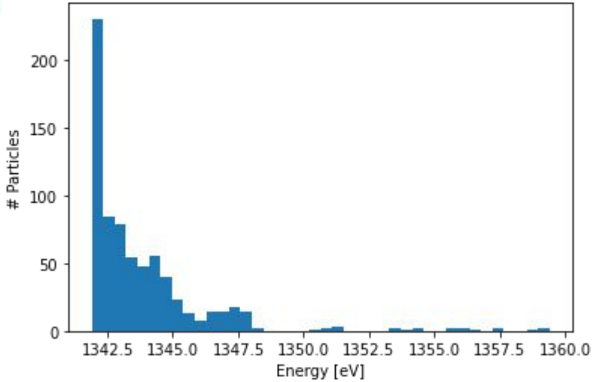
Final Energies:
1.34keV - 1.36keV

Weak Source Total Emission Length/Particle Energies:

Particle energies at the end of this length are between 1.34keV and 1.36keV



Perhaps can extend simulation chamber wall to reach the 1.36keV?



Conclusions/Inquiries:

- With changing the focus electrode and the anode potentials, can get the desired emission profile.

- Is changing the anode potential by this amount too much? Is there something I should be wary of?
- Could extend the simulation emission so that particle distribution reaches the full 1.36keV.