Progress on the Electron Gun Design for a Millan electron lens in IOTA

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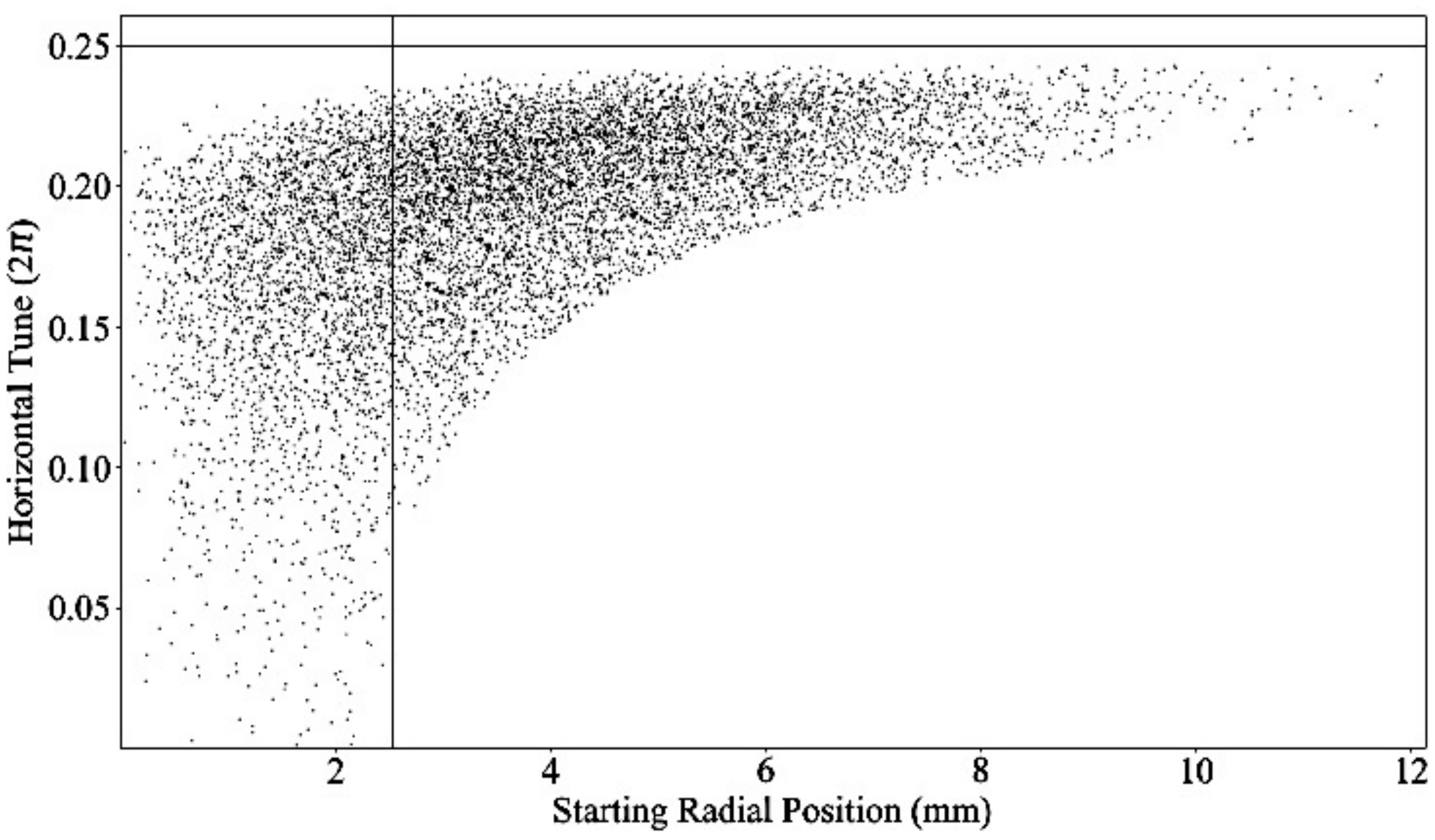
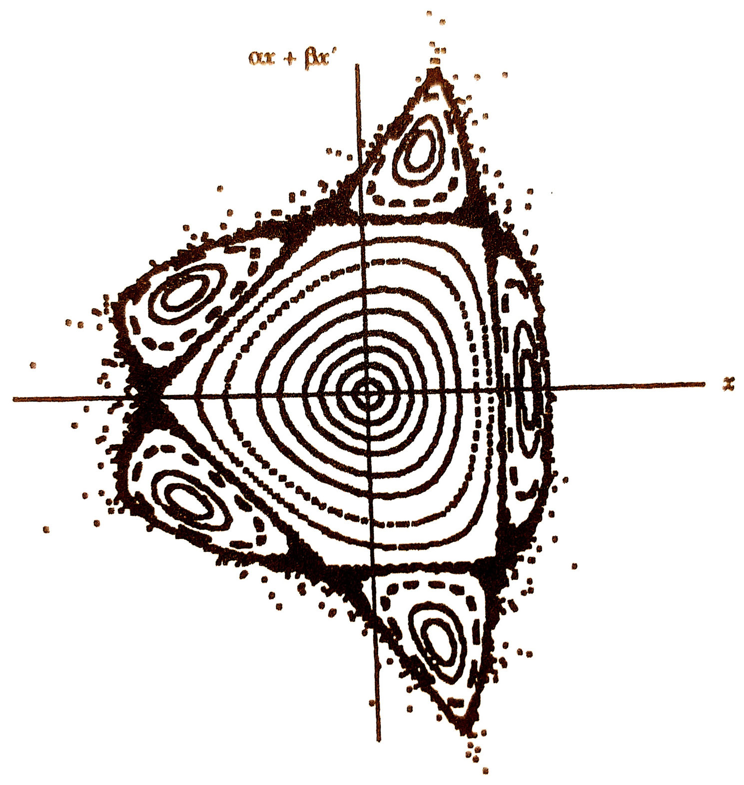
Nonlinear Optics

Landau damping is a way to mitigate beam instabilities. This is the use of tune spread to lower sensitivity to instabilities. To generate a tune spread nonlinear forces are required, such as octupole magnets. However, octupoles and other nonlinear elements can have a significant drawback in that they reduce the beam's dynamic aperture. Integrable nonlinear optics create tune spread without reducing dynamic aperture. This includes the McMillan system.

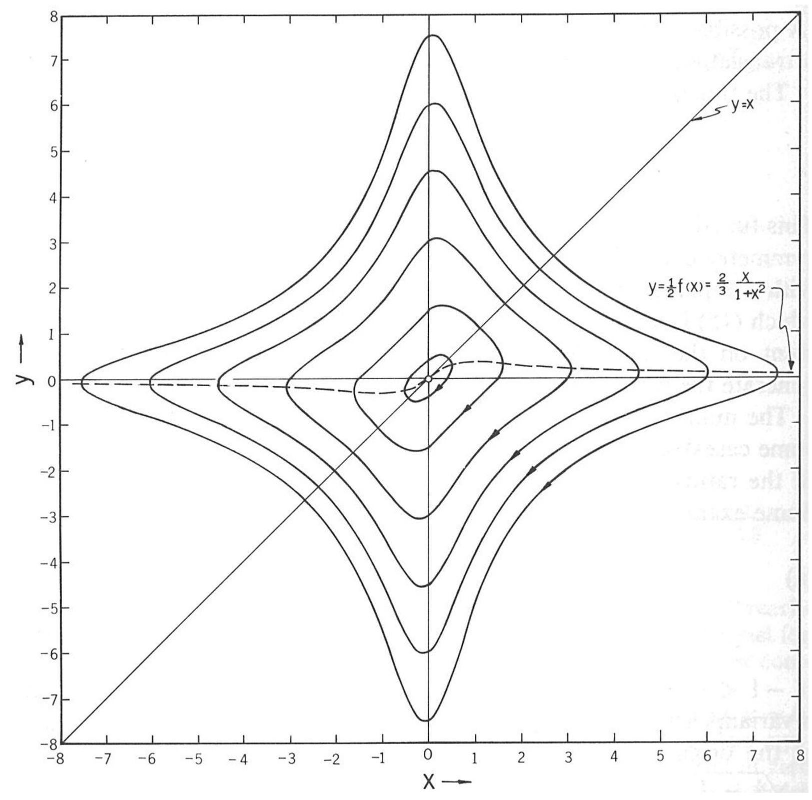
$$\begin{bmatrix} x \\ x' \\ y \\ y' \end{bmatrix}_L = \begin{bmatrix} 0 & \beta & 0 & 0 \\ -\frac{1}{\beta} & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta \\ 0 & 0 & -\frac{1}{\beta} & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ x' \\ y \\ y' \end{bmatrix}_0 \qquad \Delta r'(r) = \frac{kr}{\left(\frac{r}{a}\right)^2 + 1}$$



Theoretical particle tunes for a strong McMillan system.



Sextupole dynamic aperture (Edwards and Syphers, *An Introduction to the Physics of High Energy Accelerators*, p. 109)



Phase space of 2D McMillan system (E. McMillan, *Topics in Modern Physics*, p. 230)

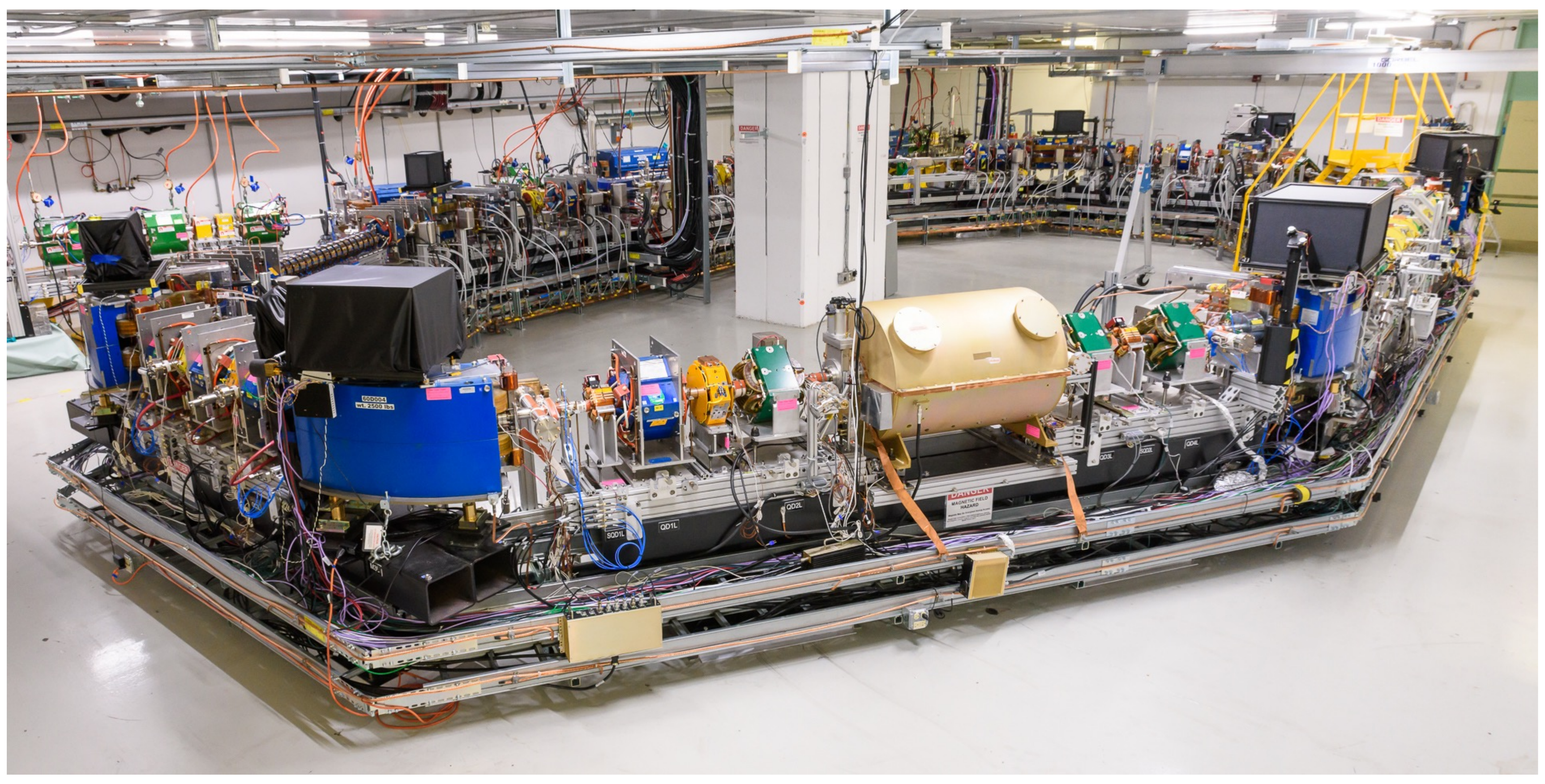
The McMillan System

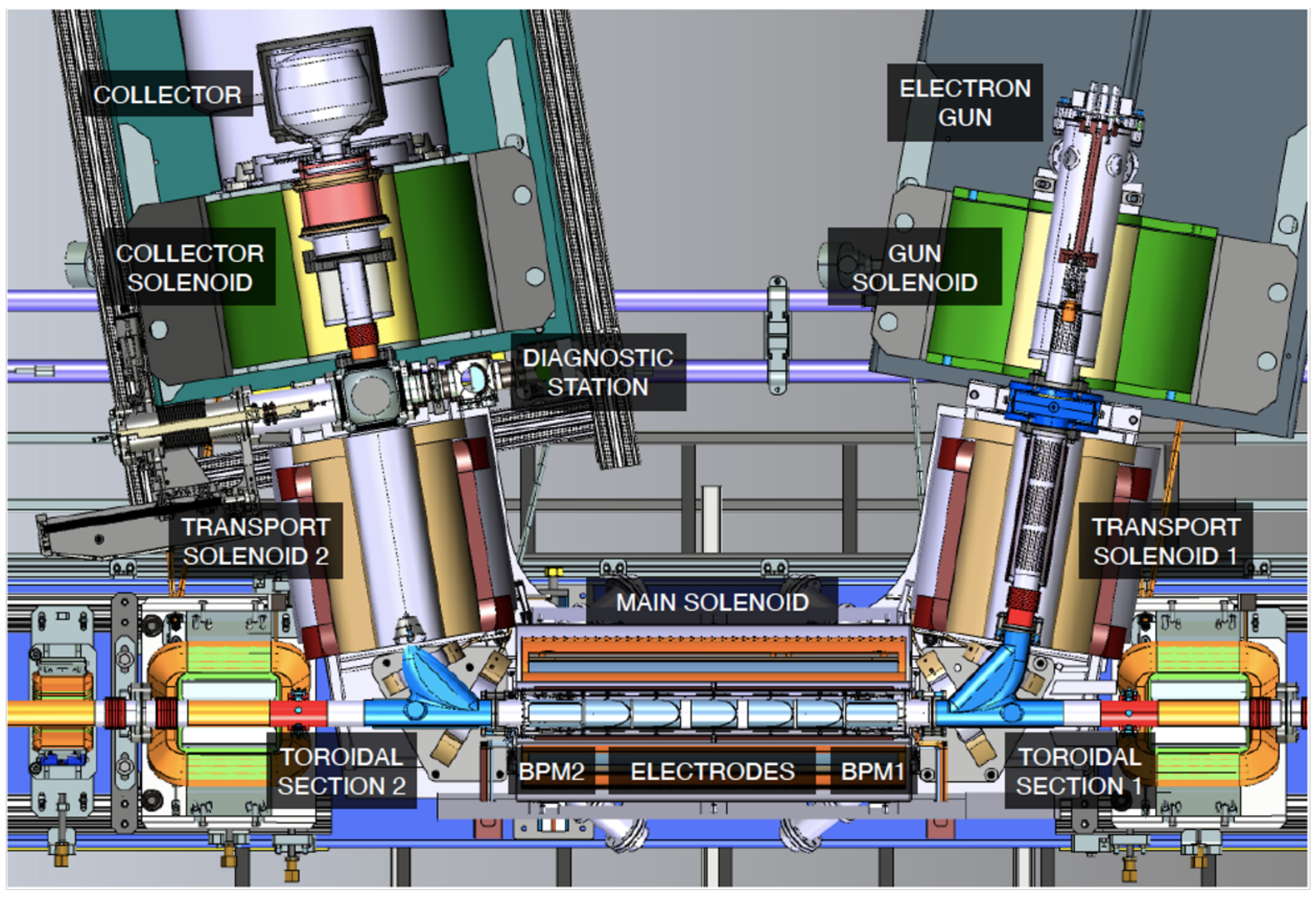
The McMillan system is a nonlinear, integrable system. It constitutes a linear transport with 0.25 phase advance followed by a radial nonlinear kick. There are two strength regimes based on the beta function: weak ($\beta k < 2$), and strong ($\beta k > 2$). It will be necessary for our lens to operate in both. We plan to have a beta function of 4m at the kick.

For a weak lens, the maximum possible tune spread is given by: $(\Delta\upsilon)_{\max} = \frac{1}{4} - \frac{1}{2\pi}\arccos\left(\frac{\beta k}{2}\right)$.

For a strong lens, particles within a certain have the potential to reach integer resonance: $r \leq a\sqrt{\frac{\beta^2 k^2}{a} - 1}$.

Integrable Optics Test Accelerator (IOTA)





IOTA electron lens schematic

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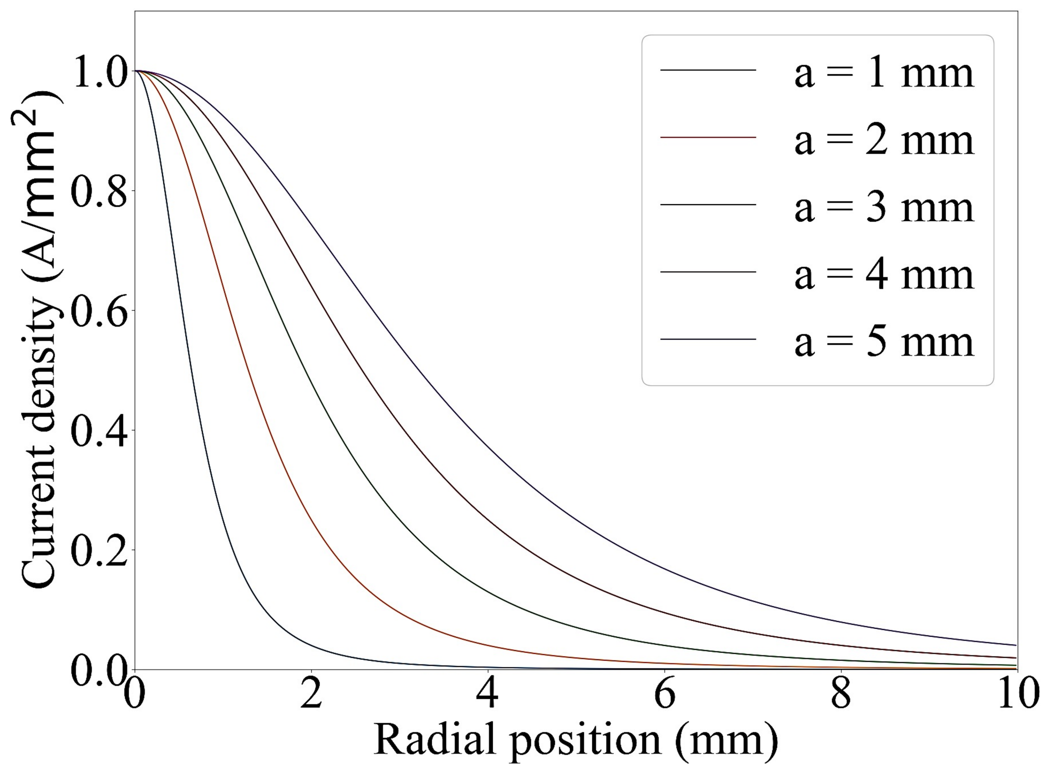
The Electron Lens

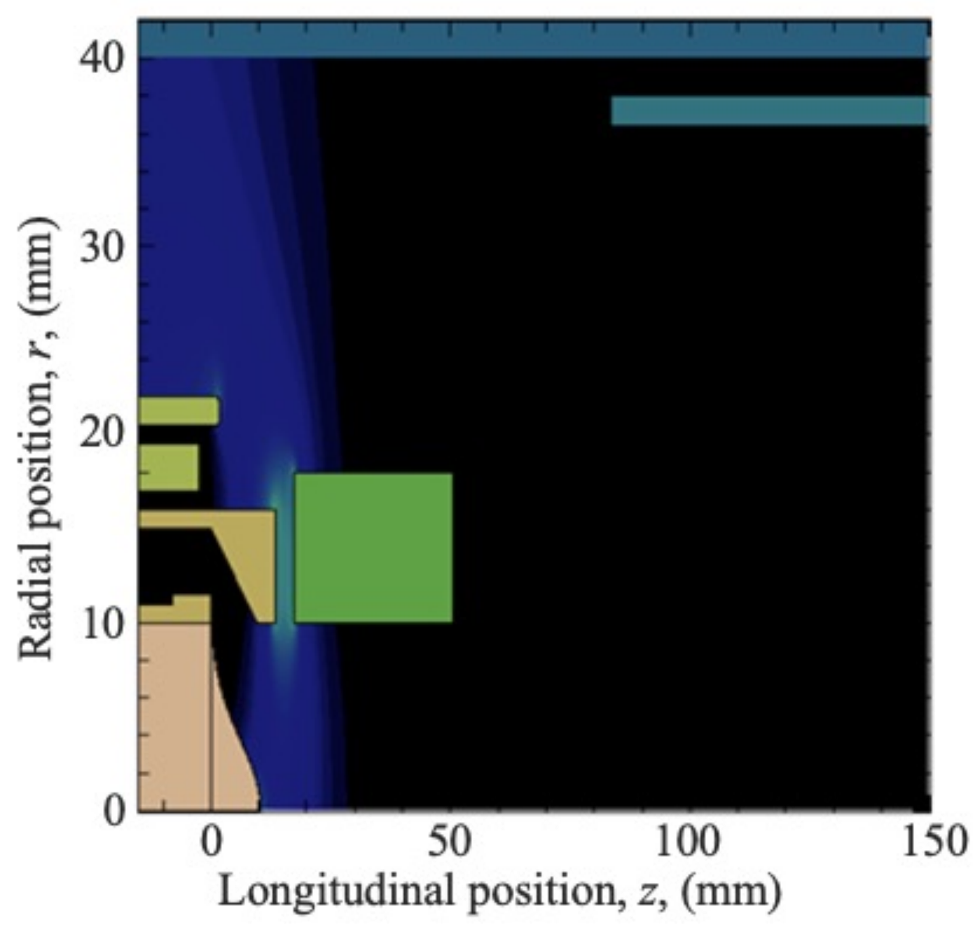
The McMillan kick can be generated with an electron lens using this current density, kick strength, and total current. The transition from a weak to strong lens occurs when $j_0 = 10\mathrm{A/cm^2}$. The desired lens radius is 10mm.

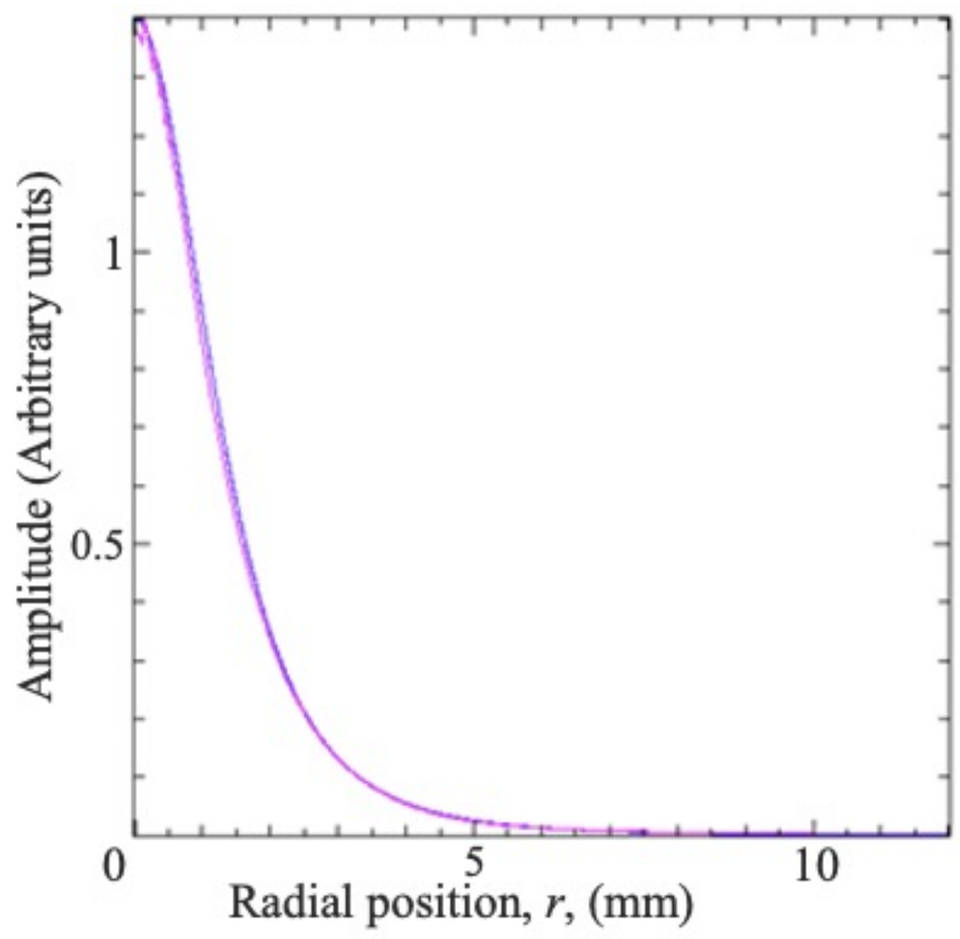
$$\boxed{j(r) = \frac{j_0 a^4}{(r^2 + a^2)^2}}$$

$$k = \frac{1}{4\pi\epsilon_0}\frac{2\pi j_0 L(1 \pm \beta_e\beta_z)}{(B\rho)_z\beta_e\beta_z c^2}$$

$$I = \pi j_0 a^2$$





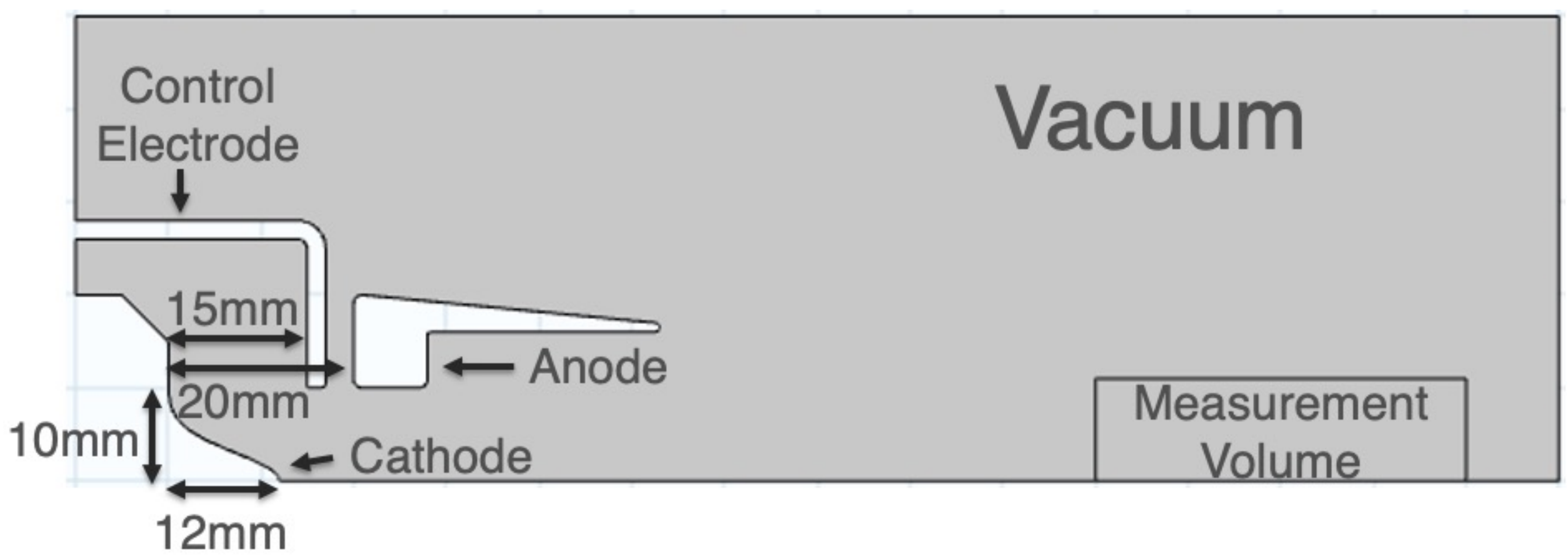


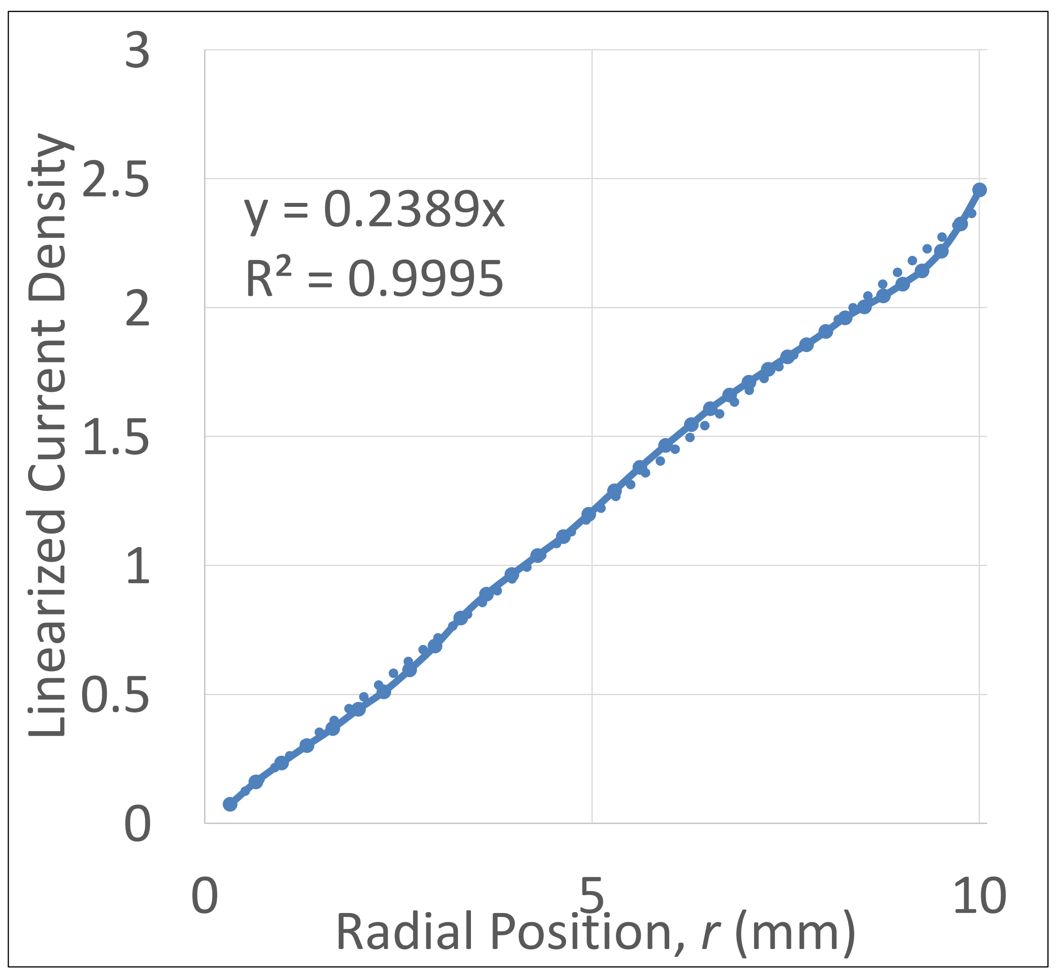
The Electron Gun Design Pt. 1

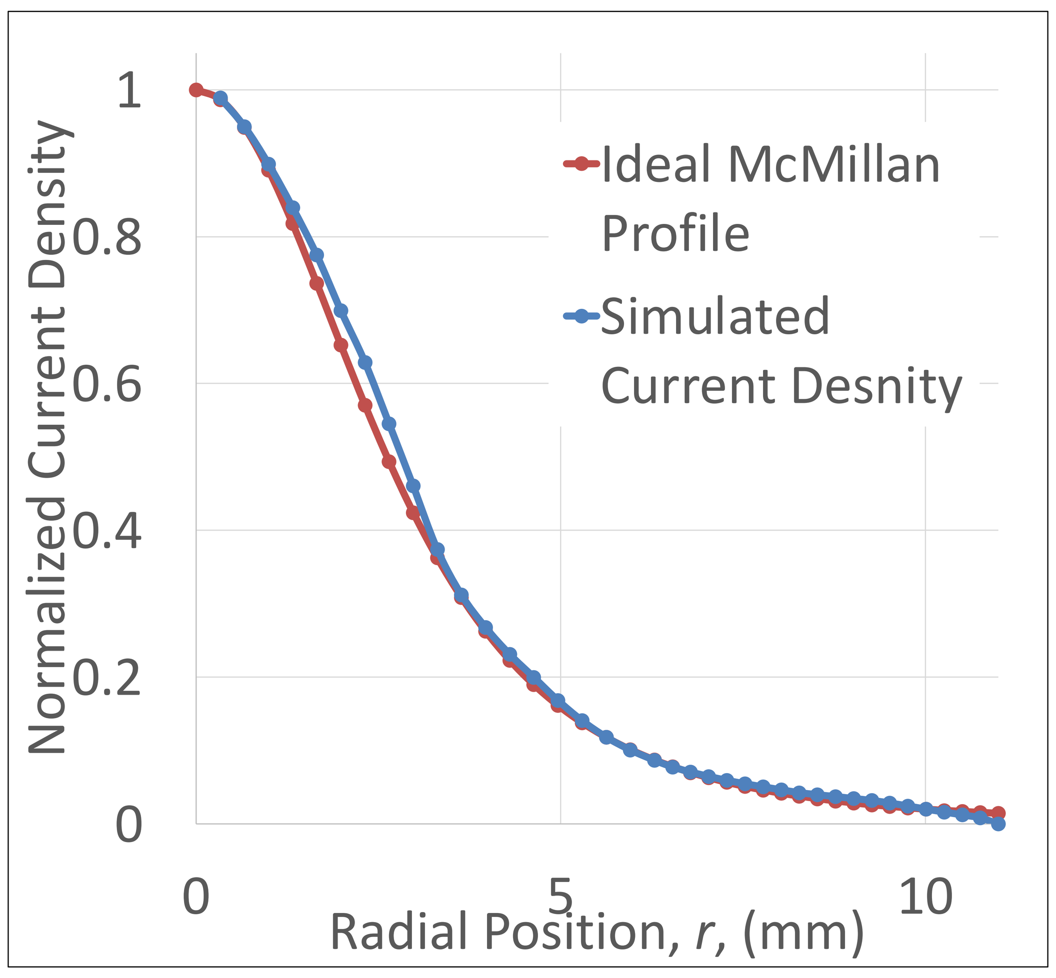
The cathode's near electric field was studied using WARP. Results showed promise using a Gaussian cathode surface. However, WARP cannot emit from such a surface. WARP is currently developing Gaussian surface emission, but design studies have continued using COMSOL.

The Electron Gun Design Pt. 2

The current best design from COMSOL is shown here. The Gaussian surface has a sigma of 3mm. The design is based off the RHIC Gaussian electron gun. Comparing COMSOL with RHIC's results recreated the current density shape, but not the total current. As such, COMSOL results are normalize for comparison.







Current density results from COMSOL simulation: Linearized results (left), comparison to ideal (right).

COMSOL Results

The McMillan current density can be linearized by: $\sqrt{\left(\frac{j_0}{j(r)}\right)^{\frac{1}{2}} - 1} = \frac{1}{a}r$. From the slope, we can find the best fit a: 4.1mm. These results show promise that the desired electron lens can be constructed from a shaped cathode.

Future Work

- Optimized gun design
- Finish system tolerance studies
- Fabricate and test gun
- Implement gun in IOTA for experimentation

References

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