Initial bend design for the IOTA electron lens

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Electron lens in IOTA

Two options for an integrable nonlinear optic using an electron lens:

1. McMillan distribution (I = 1.7 A):
   \[ j(r) = \frac{I}{\pi} \frac{a^2}{(a^2 + r^2)} \]

2. Thick-lens kicks, equal beta functions by setting
   \[ B_z = 2(B\rho)/\beta \]

Any radially symmetric distribution
Initial bend design

Design found using Python/C++ code:
- Biot-Savart integrator for axisymmetric coils
- Field line tracking

30 cm
Particle drifts

\[ \frac{dy}{ds} = \frac{B_y}{B_z} \quad \Rightarrow \quad \Delta y(s) = \int_0^s \frac{B_y(s')}{B_z(s')} \, ds' \]

Curvature B drift:

\[ \vec{v}_R = \frac{mv^2}{qR_c} \frac{\vec{R}_c \times \vec{B}}{B^2} \quad \Rightarrow \quad \Delta y(s') = \frac{2U}{v_0 \frac{|q|}{1}} \int_0^s ds' \frac{1}{R(s') B(s')} \]
Particle drifts

Field line tracking including drifts:

\[
\frac{d\vec{r}}{ds} = \pm \frac{1}{B} \left\{ \bar{B} + \frac{m}{qv_0} \frac{1}{B^2} \left( v^2_\parallel + \frac{1}{2} v^2_\perp \right) \left( \vec{B} \times \vec{\nabla}B \right) \right\}
\]
Particle drifts
Effect of space charge

Transversal motion:

Current limits (homogeneous distribution):

Transversal: \( I_{\text{brillouin}} < \frac{e}{m} v_b \pi R_b^2 B^2 \approx 821 \text{ A} \)

Longitudinal: \( I < 4\pi \varepsilon_0 \sqrt{\frac{e}{m}} U^{3/2} \left( \frac{g_1 - \sqrt{3g_2^2 - g_1^2/3}}{4g_1^2 - 9g_2^2} \right) \approx 7.9 \text{ A} \)

Rotation frequency:

Homogeneous beam, \( R=2 \text{ cm}, I = 2 \text{ A} \):
\( 3.4 \text{ MHz} \)

McMillan beam, \( a=3.6 \text{ mm}, I = 1.7 \text{ A} \):
\( 2.4 - 92 \text{ MHz} \)

Amount of oscillation:
\[ r = \frac{1}{\varepsilon_0} \frac{m I}{e v} \frac{1}{\pi R_b^2 B^2} r_0 \]
Simulation with space charge

Fixed to:

\[ \phi(r) = -\frac{1}{2\pi\varepsilon_0} \frac{I}{v} \left\{ \ln\left( \frac{R_b}{R} \right) + \frac{1}{2} \left( 1 + \frac{a^2}{R_b^2} \right) \ln\left( \frac{a^2 + r^2}{a^2 + R_b^2} \right) \right\} \]

- \( r \leq R_b \)
- \( R_b \leq r < R \)

Neumann boundary conditions

Beam pipe with constant curvature
Simulation with space charge

192 processors
9 h on intel12 / Wilson cluster
≈ 0.5 mm grid spacing, 24e6 dofs
≈ 10e6 particles
Simulation with space charge

- For the McMillan distribution: 2.9 % (no sc) ... 6.4 % (1.7 A) ... 12.9 % (3.4 A) rms deviation
- Kick maps were produced from the potential / electric field from the simulation
Simulation with space charge
Conclusion and outlook

• An initial design of the bending section of the IOTA electron lens was performed.
• Simulations with and without space charge were made to understand the transport
• Open questions for future research:
  – Better understand and better quantify the aberration in the beam distribution
  – Study influence of the distribution at the electron gun on the transport
  – Investigate different beam pipe geometries in the bends
  – Magnetic flux into adjacent IOTA quadrupoles? Influence of the magnetic field of the ion pumps?
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Thank you for your attention!