Initial bend design for the IOTA electron lens

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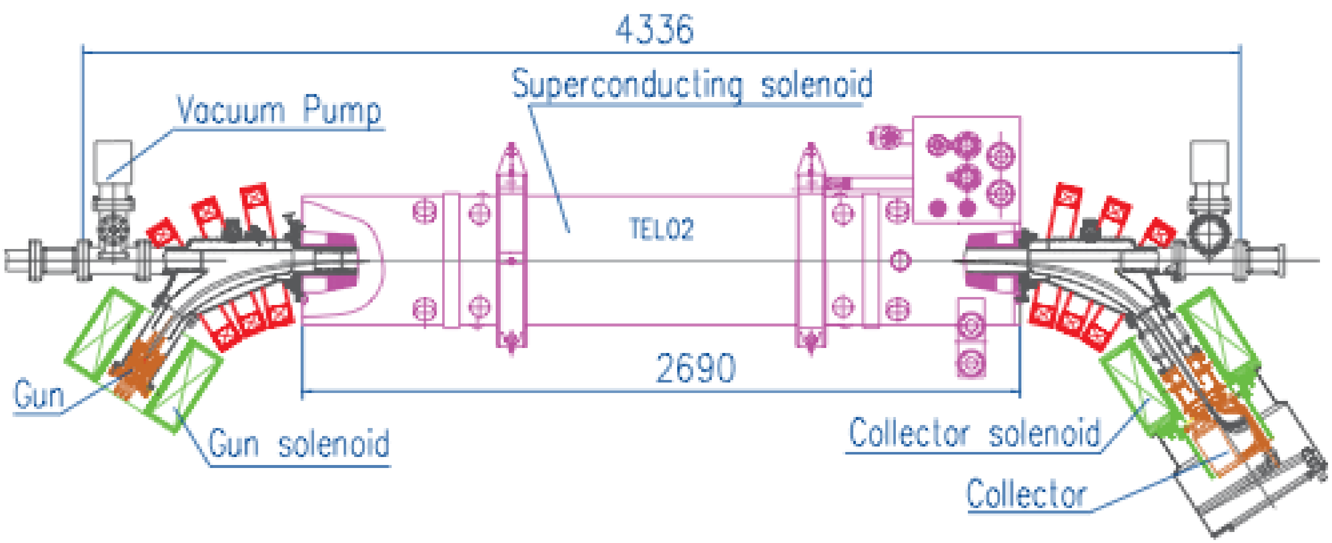
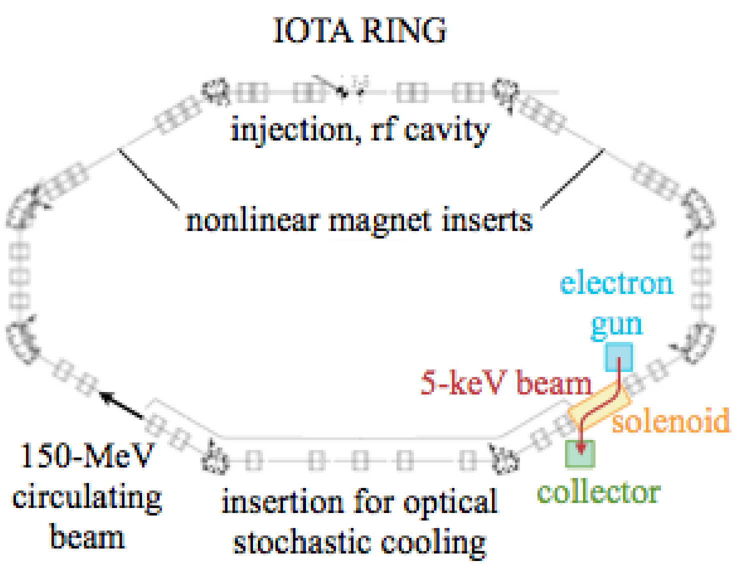
Electron lens in IOTA





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

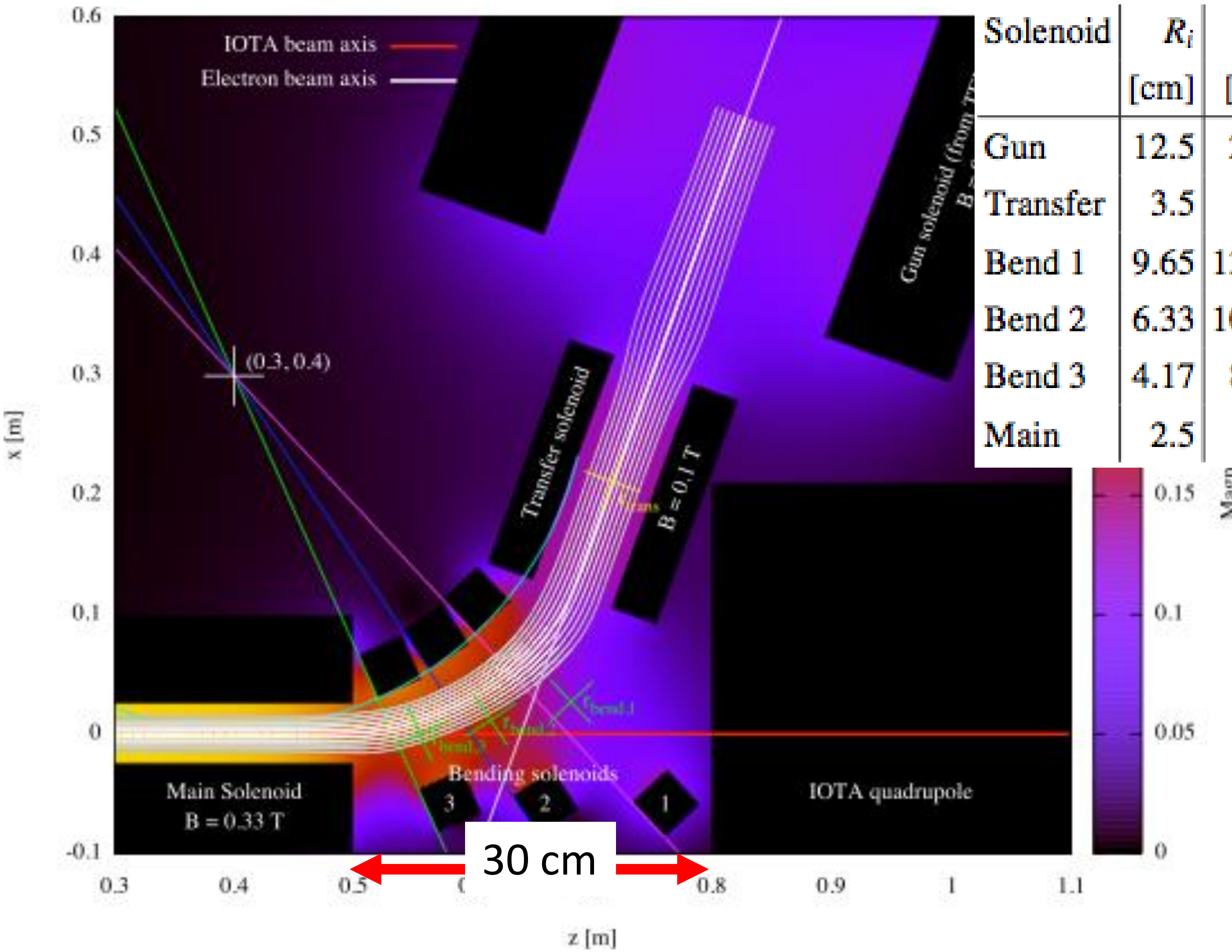
1. McMillan distribution (I = 1.7 A):

$$j(r) = \frac{I}{\pi} \frac{a^2}{(a^2 + r^2)}$$

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

   Any radially symmetric distribution

Initial bend design



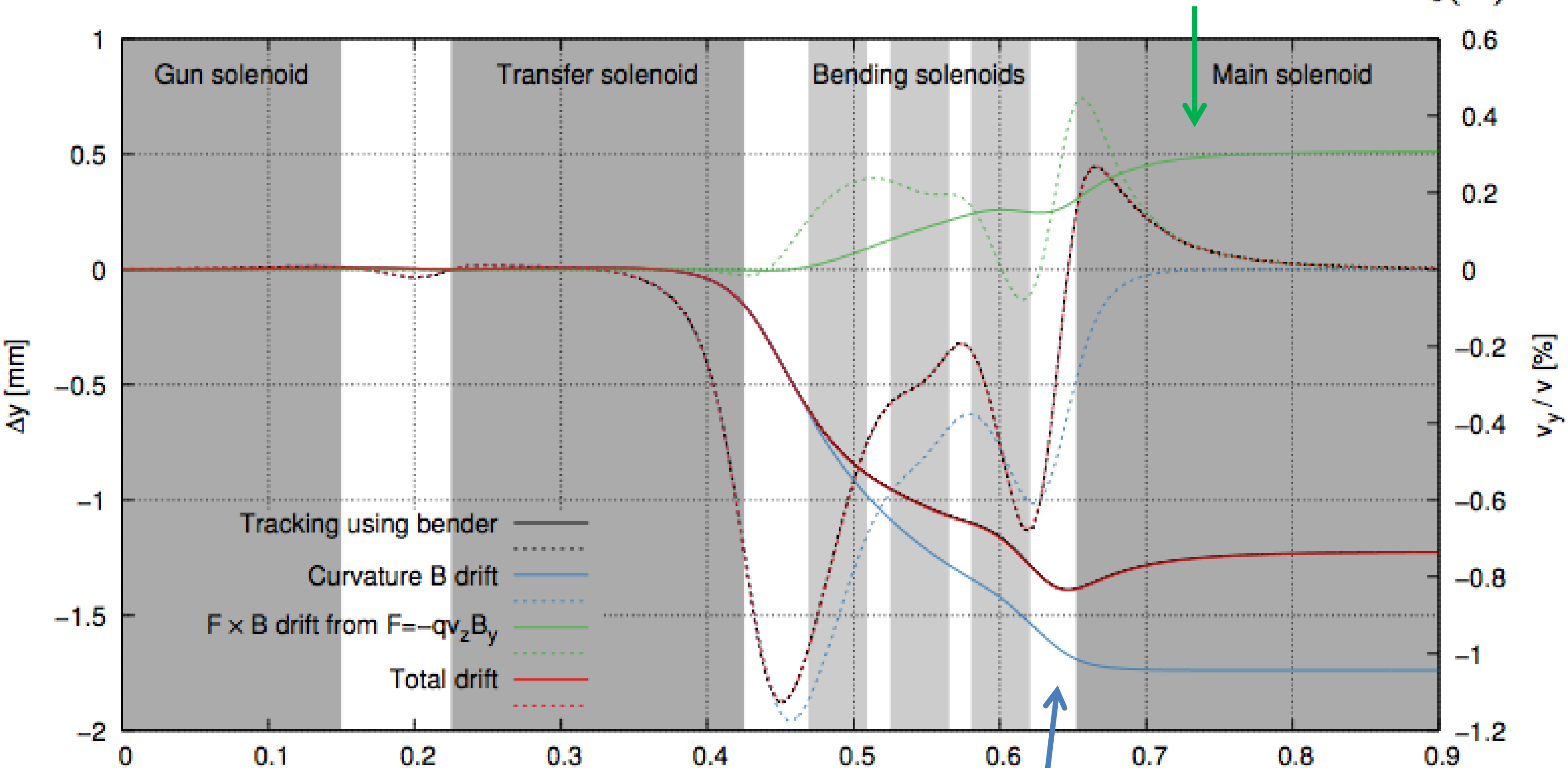
Solenoid	R_i [cm]	R_o [cm]	B [mT]	j [A/mm^2]	Θ [°]
Gun	12.5	23.7	100	1.11	70
Transfer	3.5	7.5	100	2.27	70
Bend 1	9.65	13.65	53.9	6.28	43
Bend 2	6.33	10.33	74.9	6.28	33.5
Bend 3	4.17	8.17	100	6.28	24
Main	2.5	10	330	3.53	

Design found using Python/C++ code:

- Biot-Savart integrator for axisymmetric coils
- Field line tracking

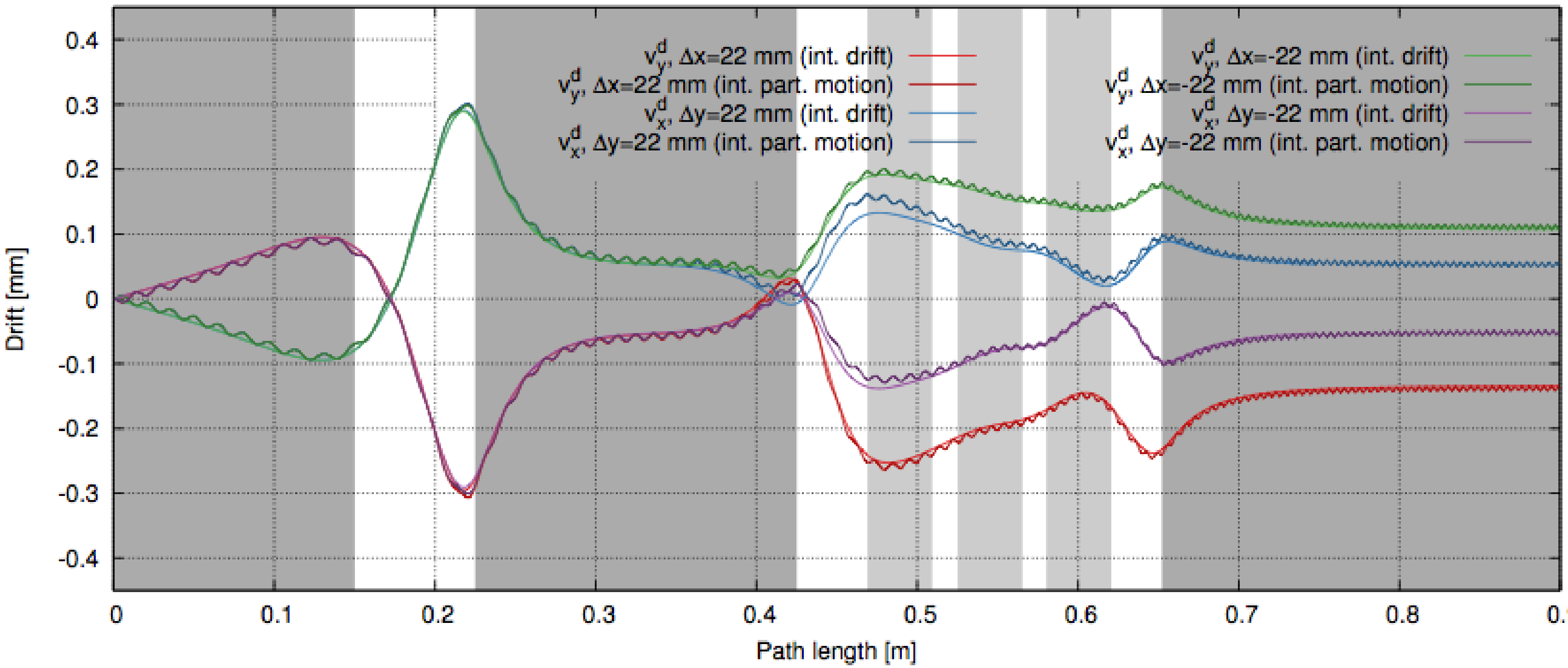
Particle drifts

$$\frac{\mathrm{d}y}{\mathrm{d}s} = \frac{B_y}{B_z} \longrightarrow \Delta y(s) = \int_0^s \mathrm{d}s' \frac{B_y(s')}{B_z(s')}$$



Curvature B drift: $\vec{v}_R = \frac{m v_\parallel^2}{q R_c} \frac{\vec{R}_c \times \vec{B}}{B^2} \longrightarrow \Delta y(s) = \frac{2U}{v_0} \frac{q}{|q|} \int_0^s \mathrm{d}s' \frac{1}{R(s') B(s')}$

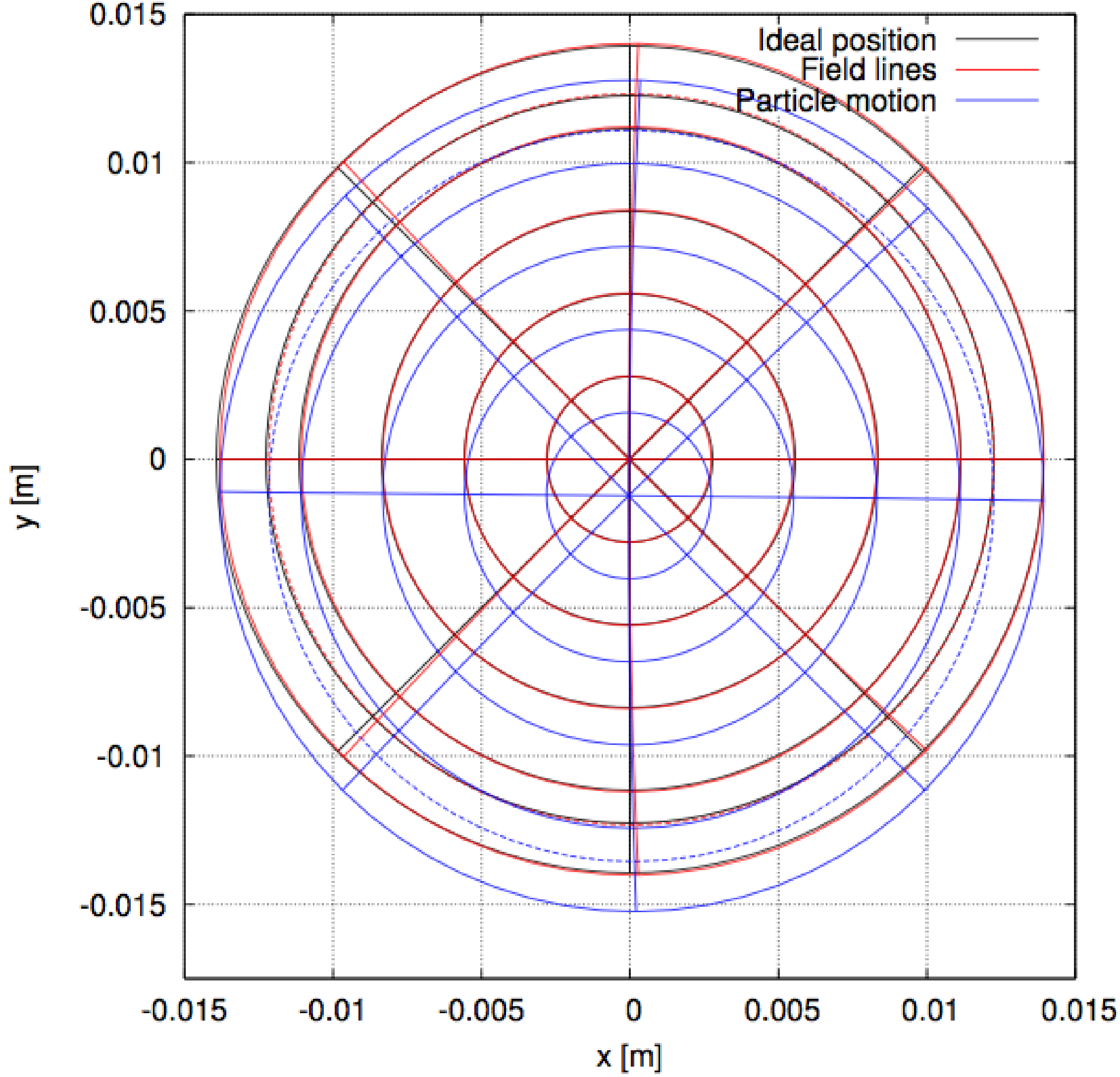
Particle drifts



Field line tracking including drifts:

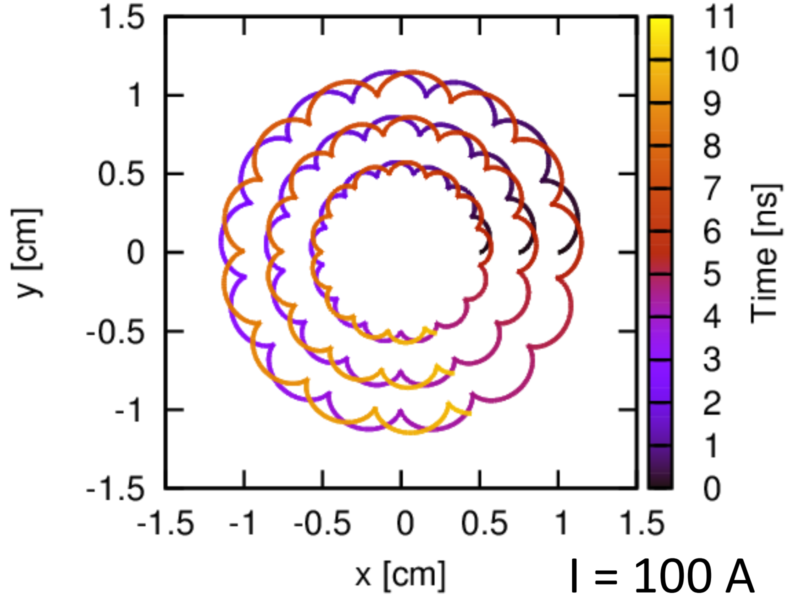
$$\frac{\mathrm{d}\vec{r}}{\mathrm{d}s} = \pm\frac{1}{B}\left\{\vec{B} + \frac{m}{qv_0}\frac{1}{B^2}\left(v_{\parallel}^2 + \frac{1}{2}v_{\perp}^2\right)\left(\vec{B}\times\vec{\nabla}B\right)\right\}$$

Particle drifts



Effect of space charge

Transversal motion:



I = 100 A

Rotation frequency:

Homogeneous beam, R=2 cm, I = 2 A:
3.4 MHz

McMillan beam, a=3.6 mm, I = 1.7 A:
2.4 – 92 MHz

Amount of oscillation:

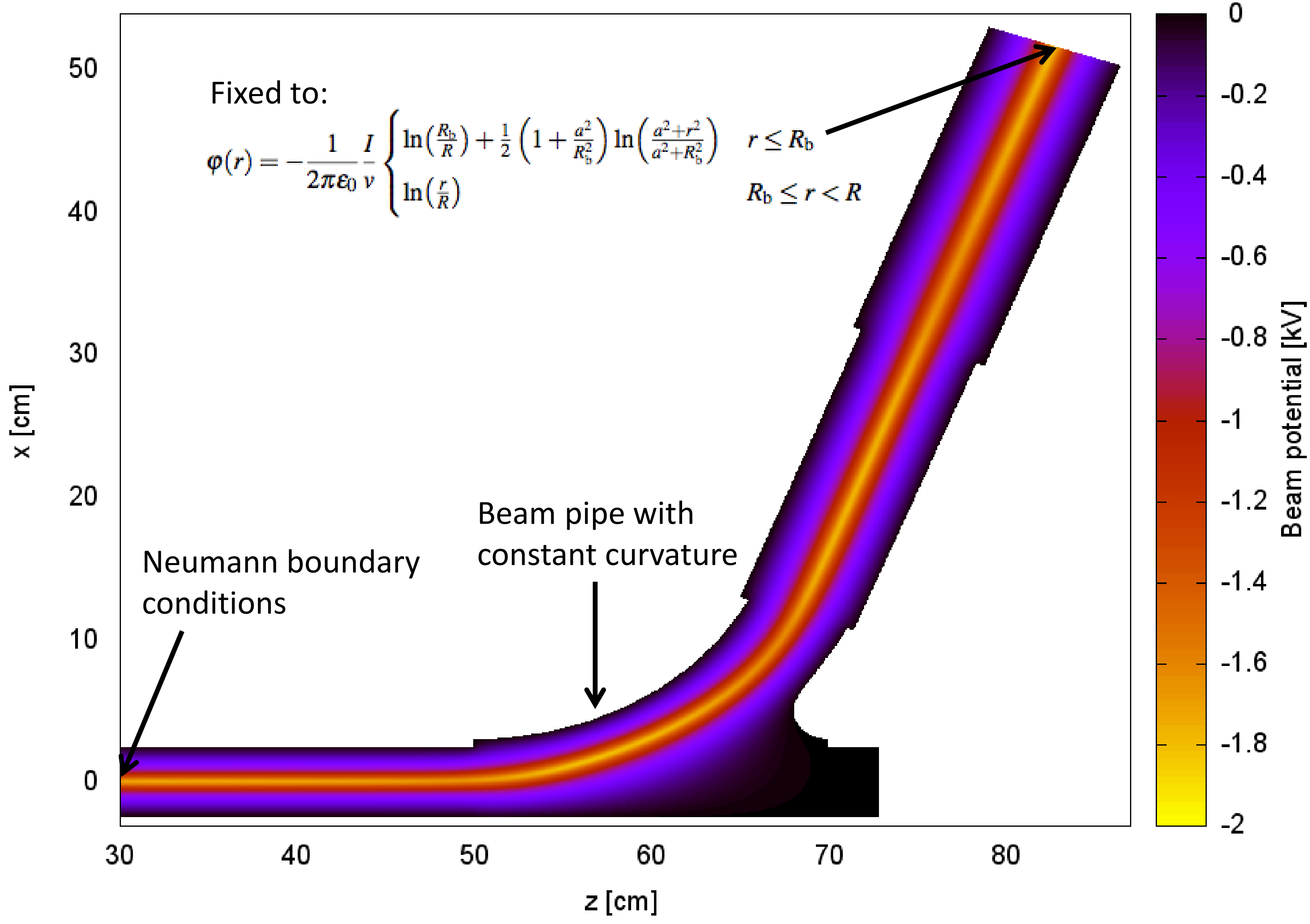
$$r = \frac{1}{\varepsilon_0} \frac{m}{e} \frac{I}{v} \frac{1}{\pi R_\mathrm{b}^2} \frac{1}{B^2} r_0$$

Current limits (homogeneous distribution):

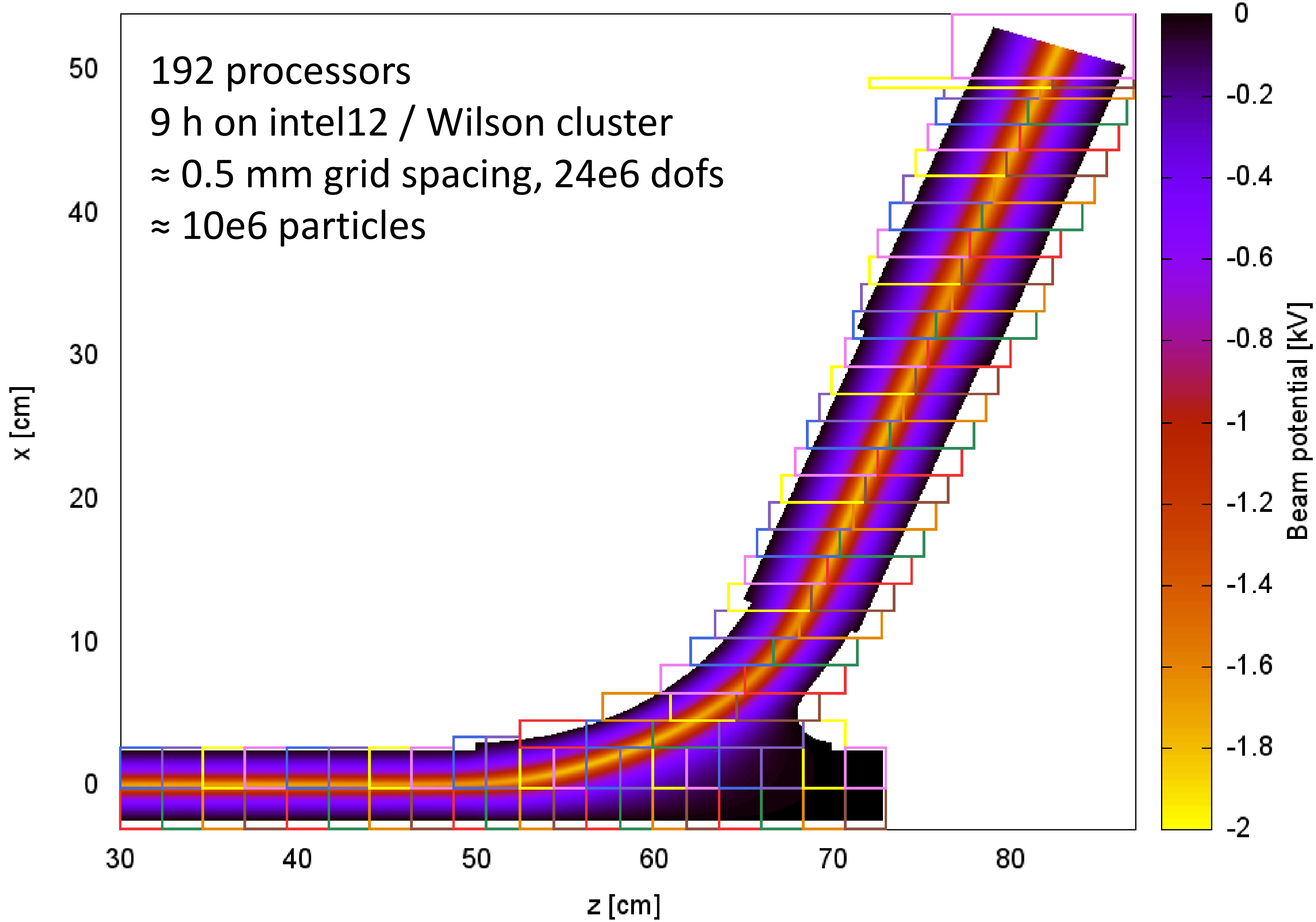
Transversal: $I_\mathrm{brillouin} < \frac{e}{m} v_\mathrm{b} \pi R_\mathrm{b}^2 B^2 \approx 821\,\mathrm{A}$

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

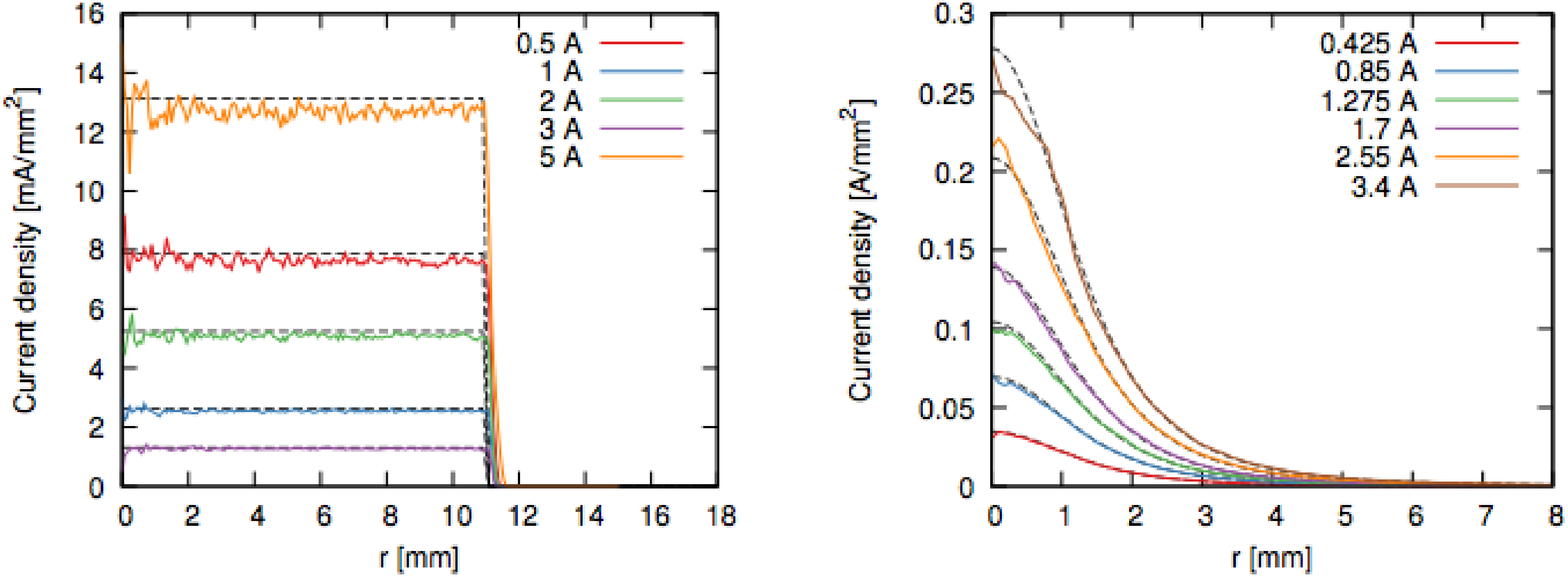
Simulation with space charge



Simulation with space charge

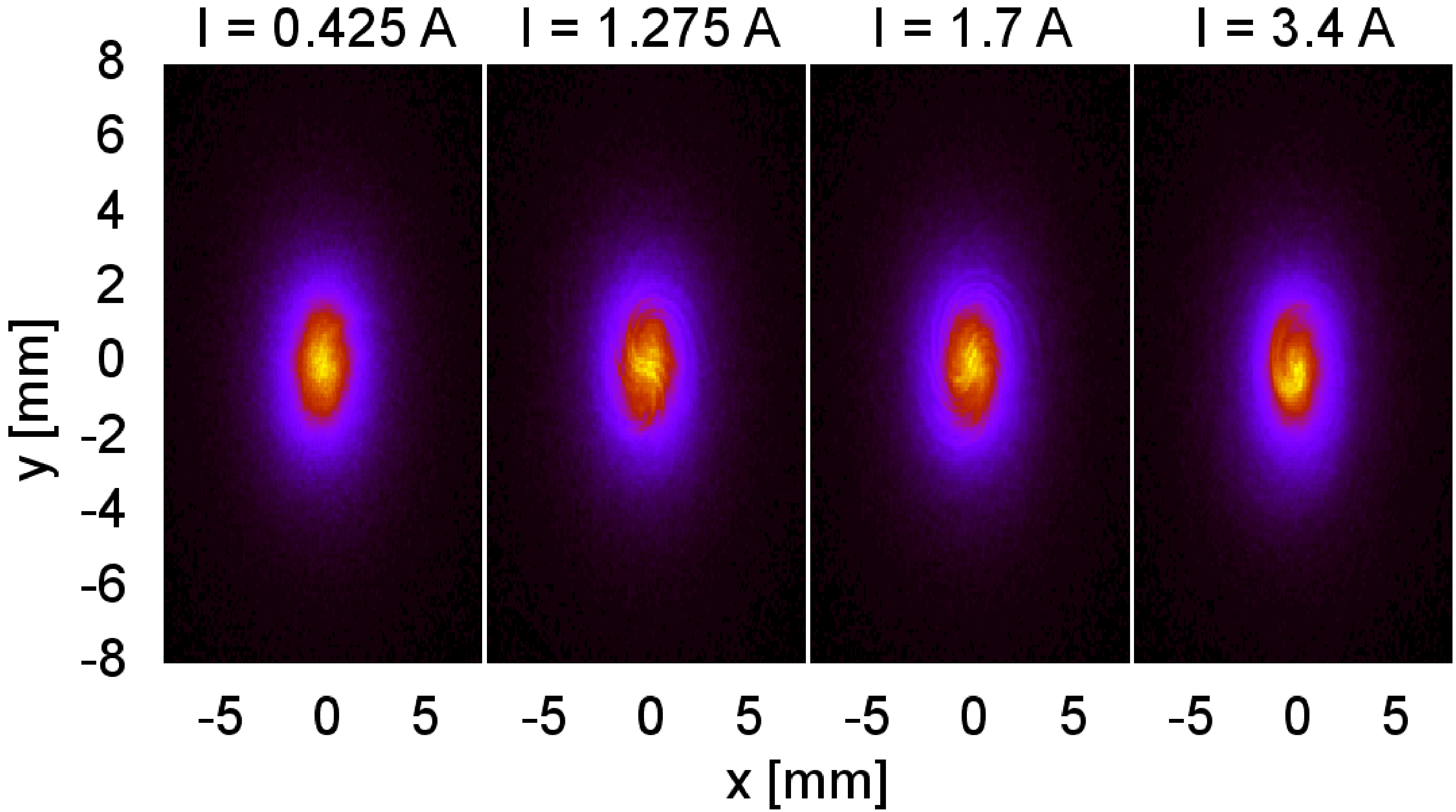


Simulation with space charge



- 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!