100keV Gun Test Stand

Design and Parameter Study

Internal Note SLS-TME-TA-2004-0244
http://slsbd.psi.ch/pub/slsnotes/

Topics

- Gun Geometries
- Parameter Studies
  - Solenoid Field
  - Diode Gap
  - Bunch Charge
  - Bunch Length
  - Active Emitter Area
- Scaling Laws and Extrapolation
- Projected Emittance and Slice Emittance
- Conclusions

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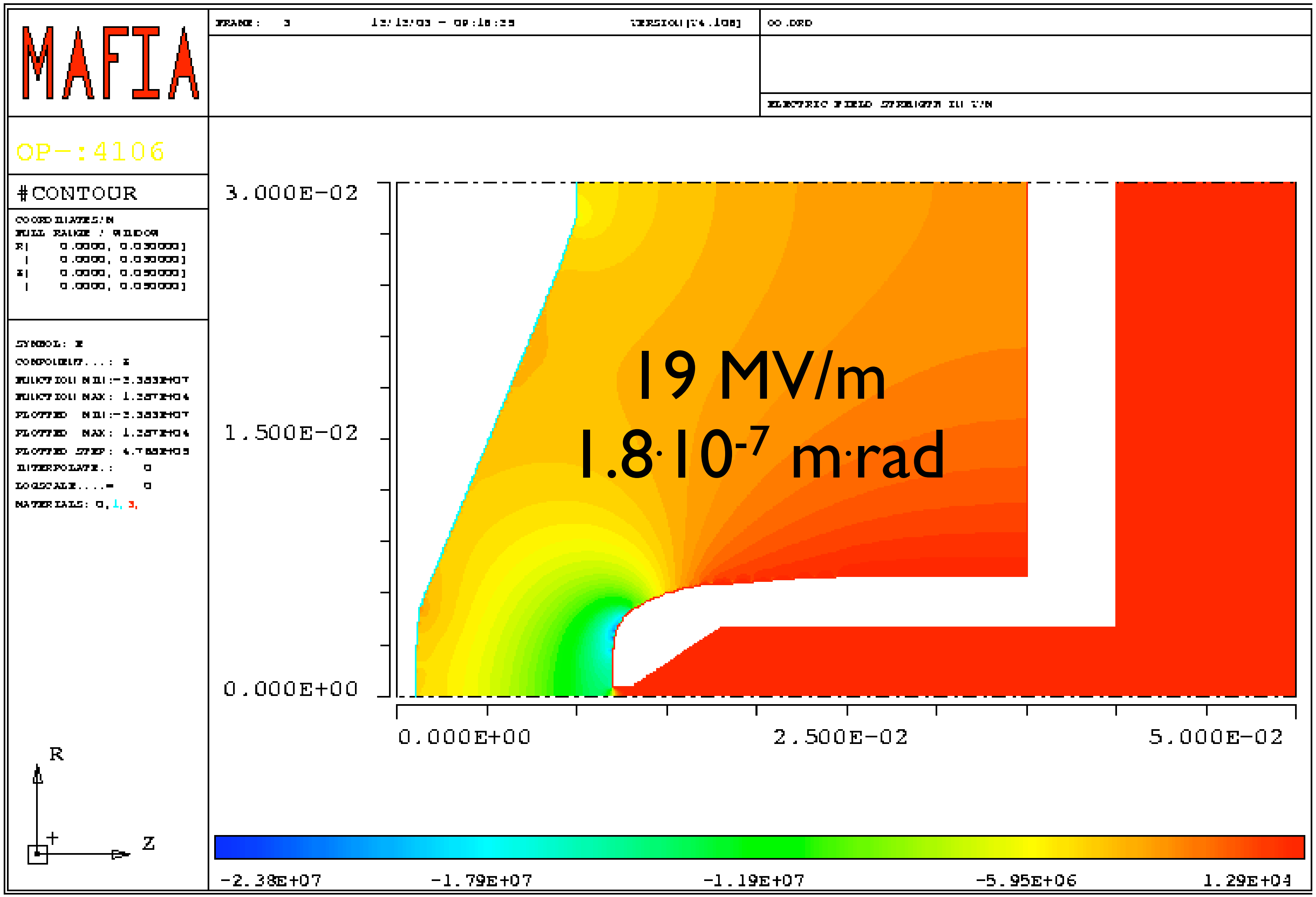
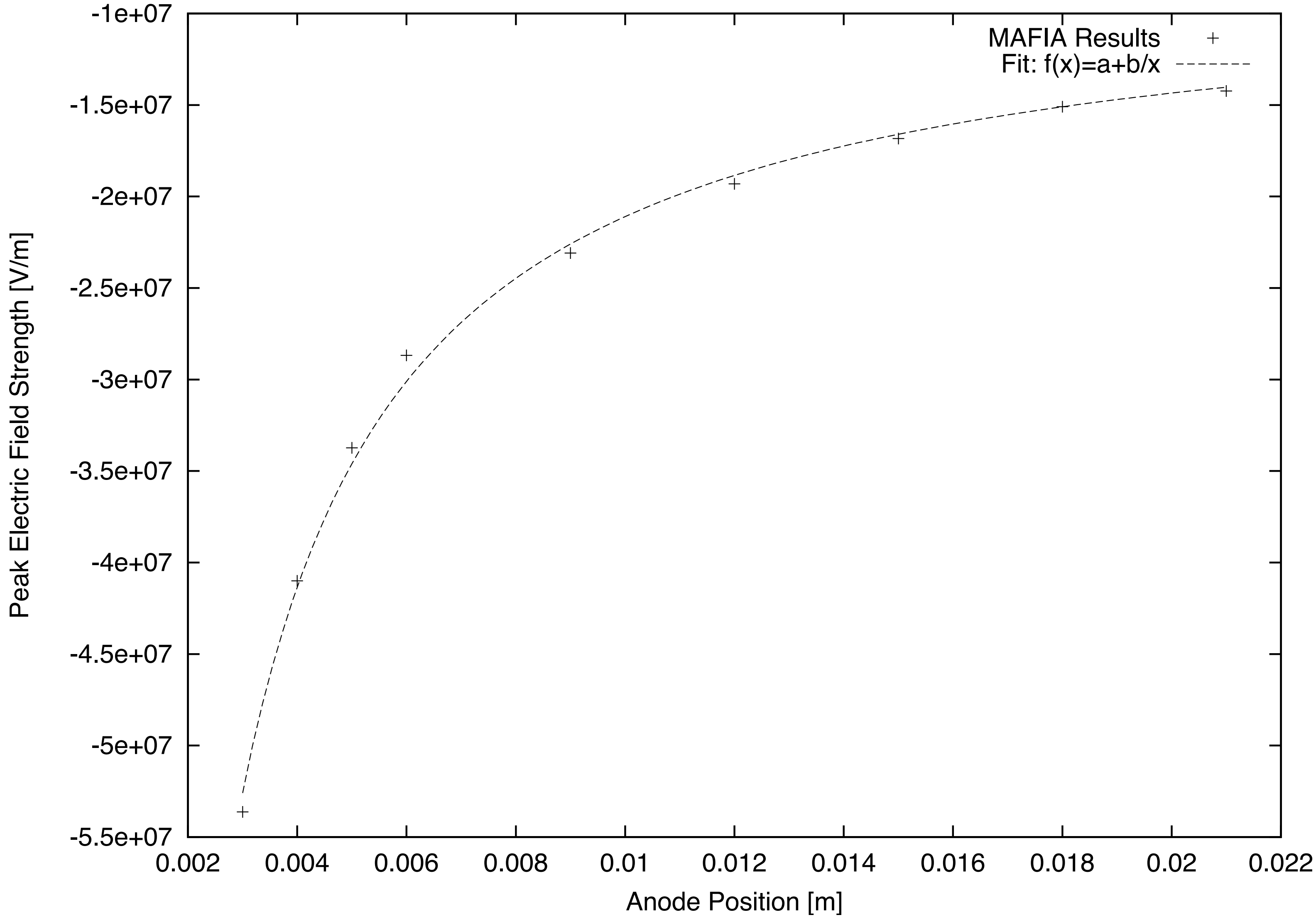
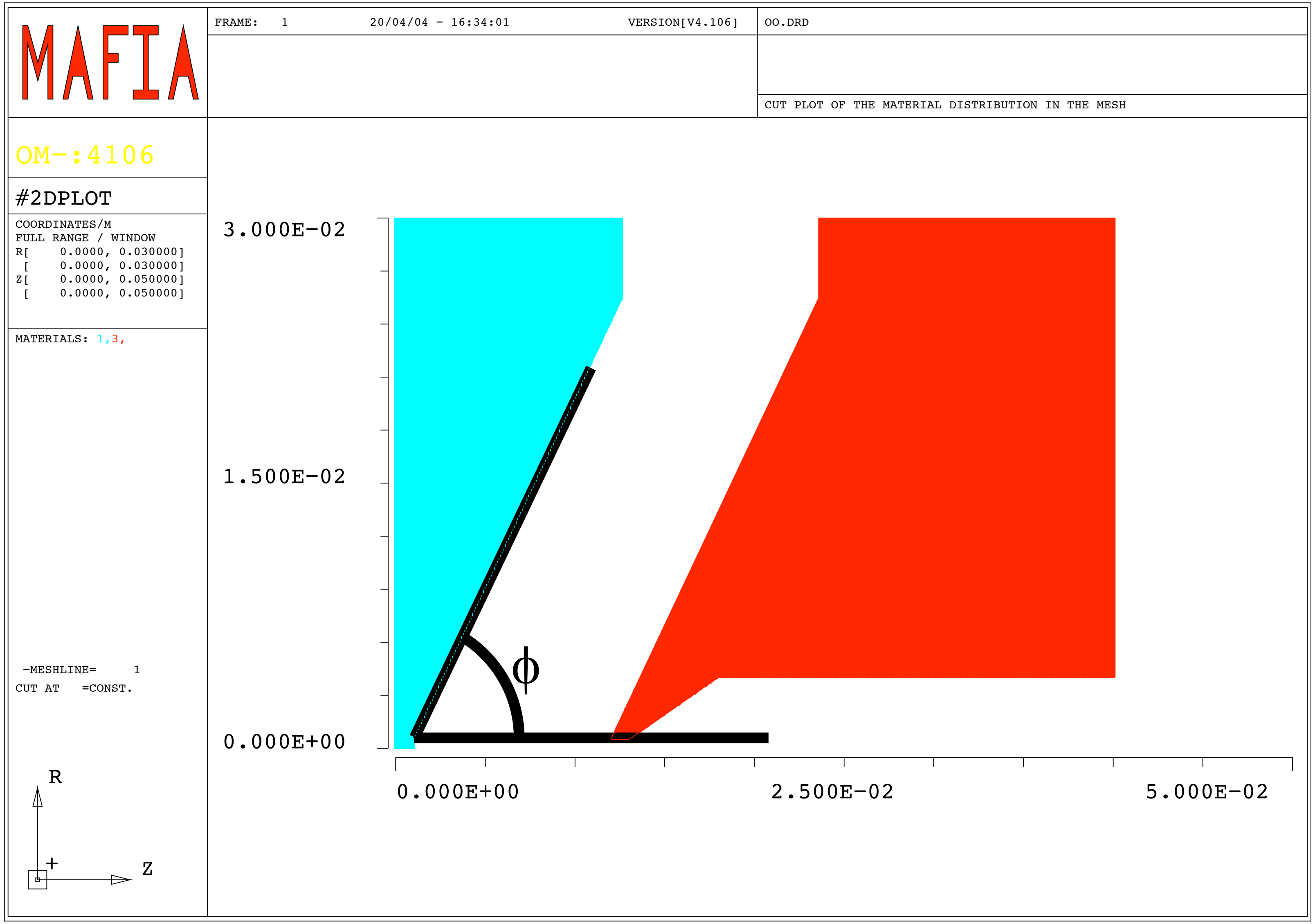
The First Gun Design Suggestion



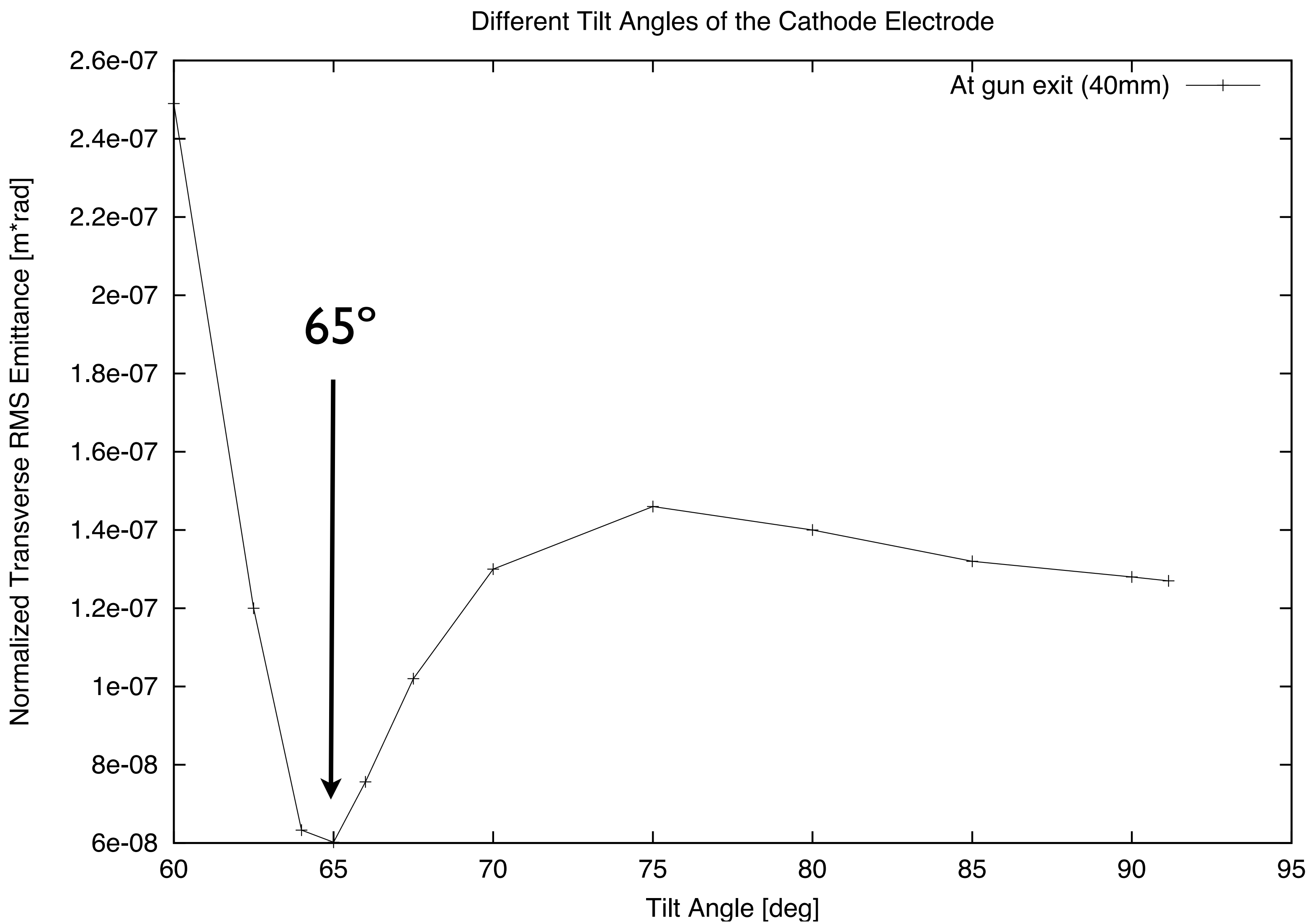
Peak Electric Field Strength



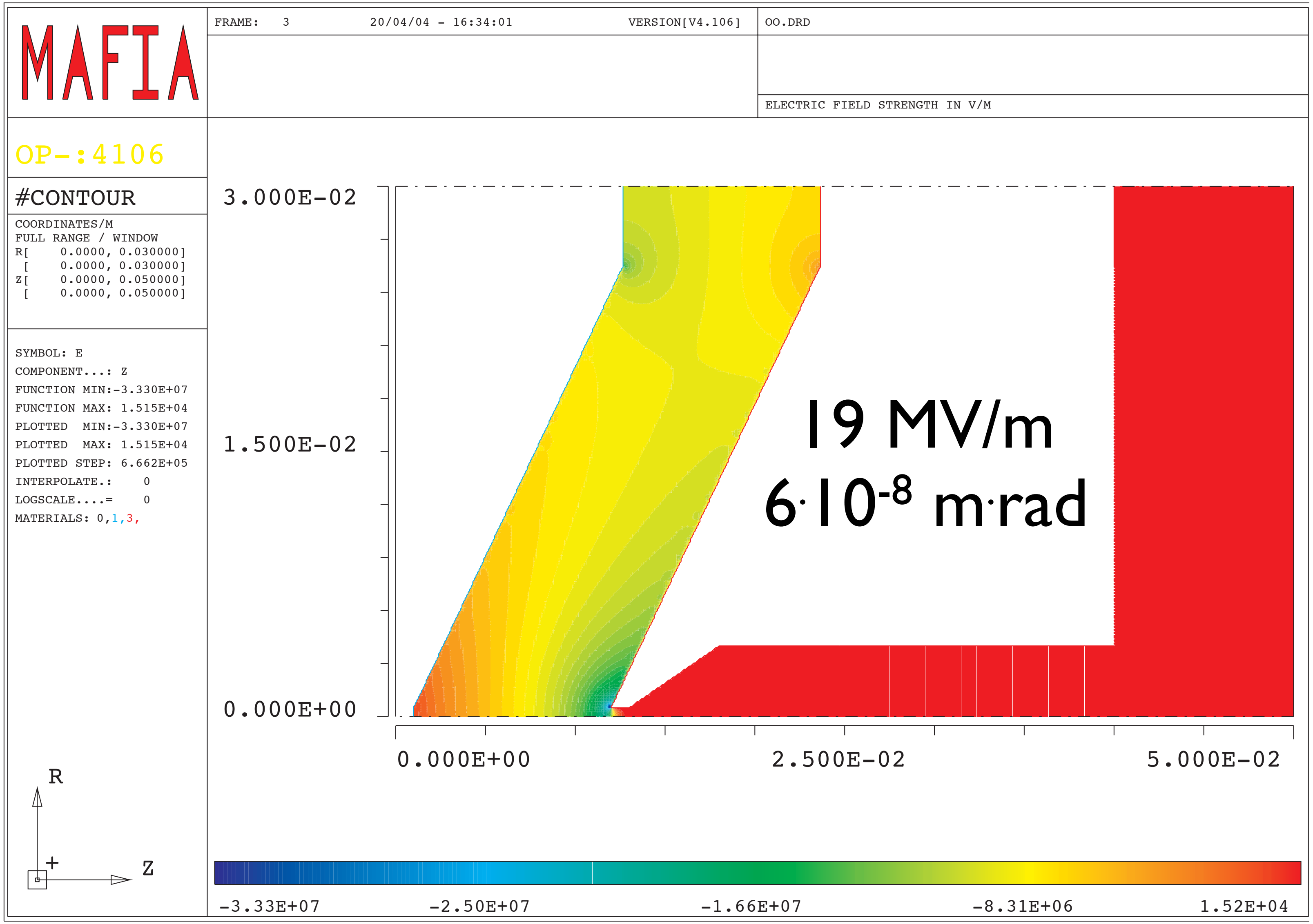
A Simplified Design



Optimizing the Cathode Tilt Angle



The Resulting Improved Design



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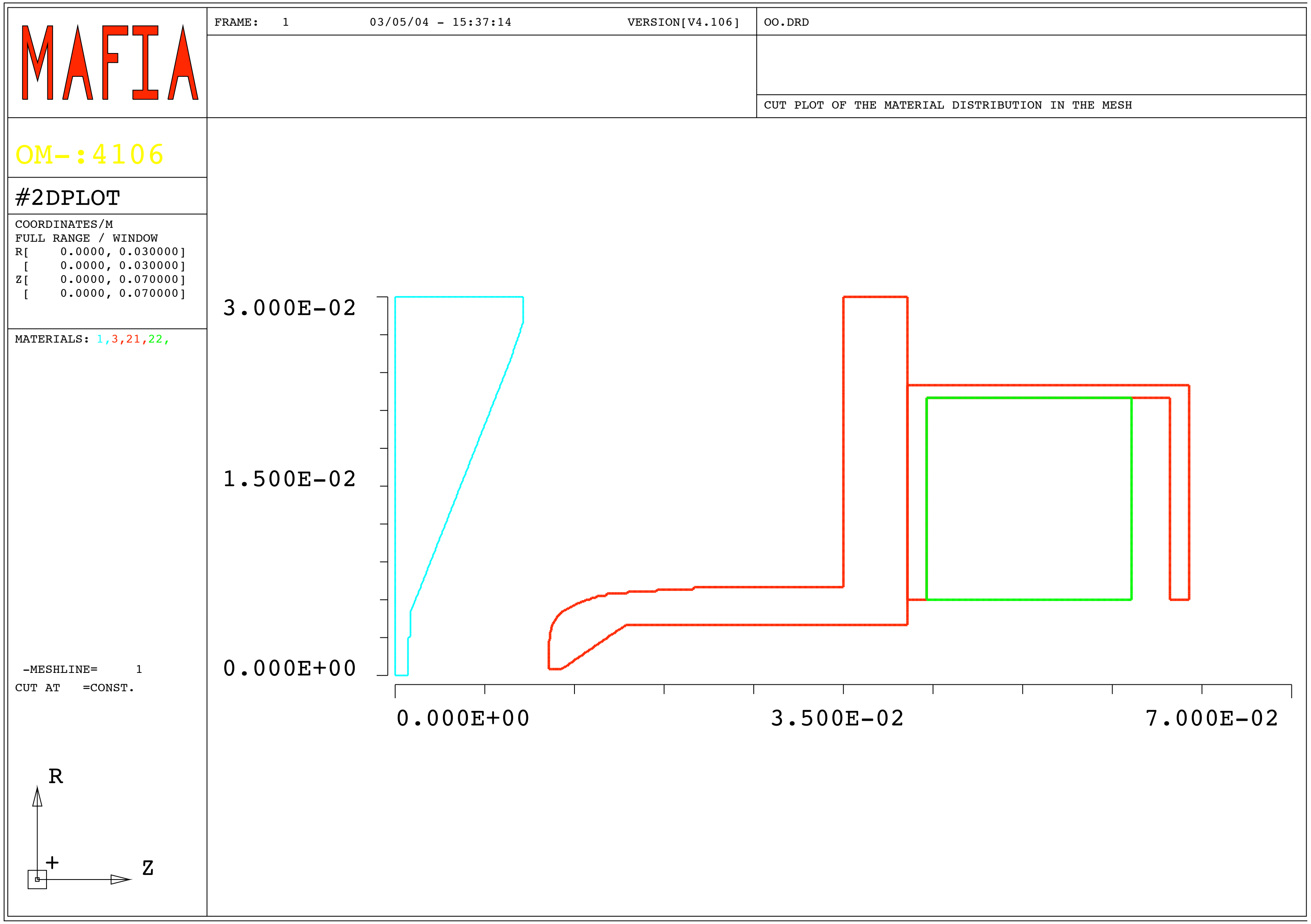
Input Parameters

- Cathode Potential: -100kV
- Active Emitter Radius: r_{act}=100μm
- Pulse: Gaussian, cut-off at $\pm 3\sigma_t$, σ_t=20ps, $Q \approx -5 \cdot 10^{-12}$C ($\hat{I}$=100mA)
- Initial Energy: γ_0=1.0001, initial divergence is set to zero
- Iris: r_{iris}=500μm
- Tracked Macro-Particles: N=20000
- Tracked Path: From the cathode surface at z_0=1mm to the end of the drift section at z=342mm

Input Geometry



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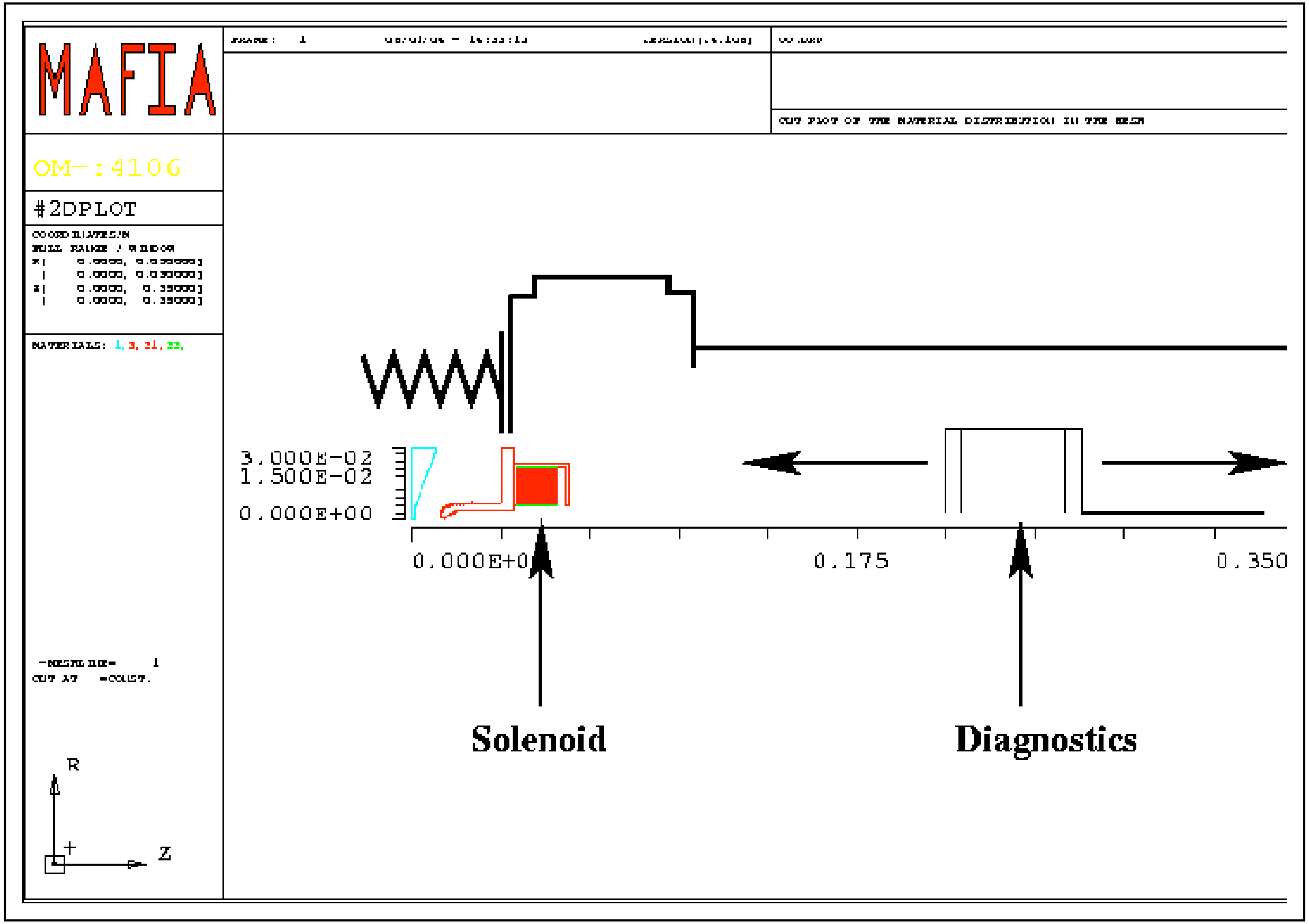
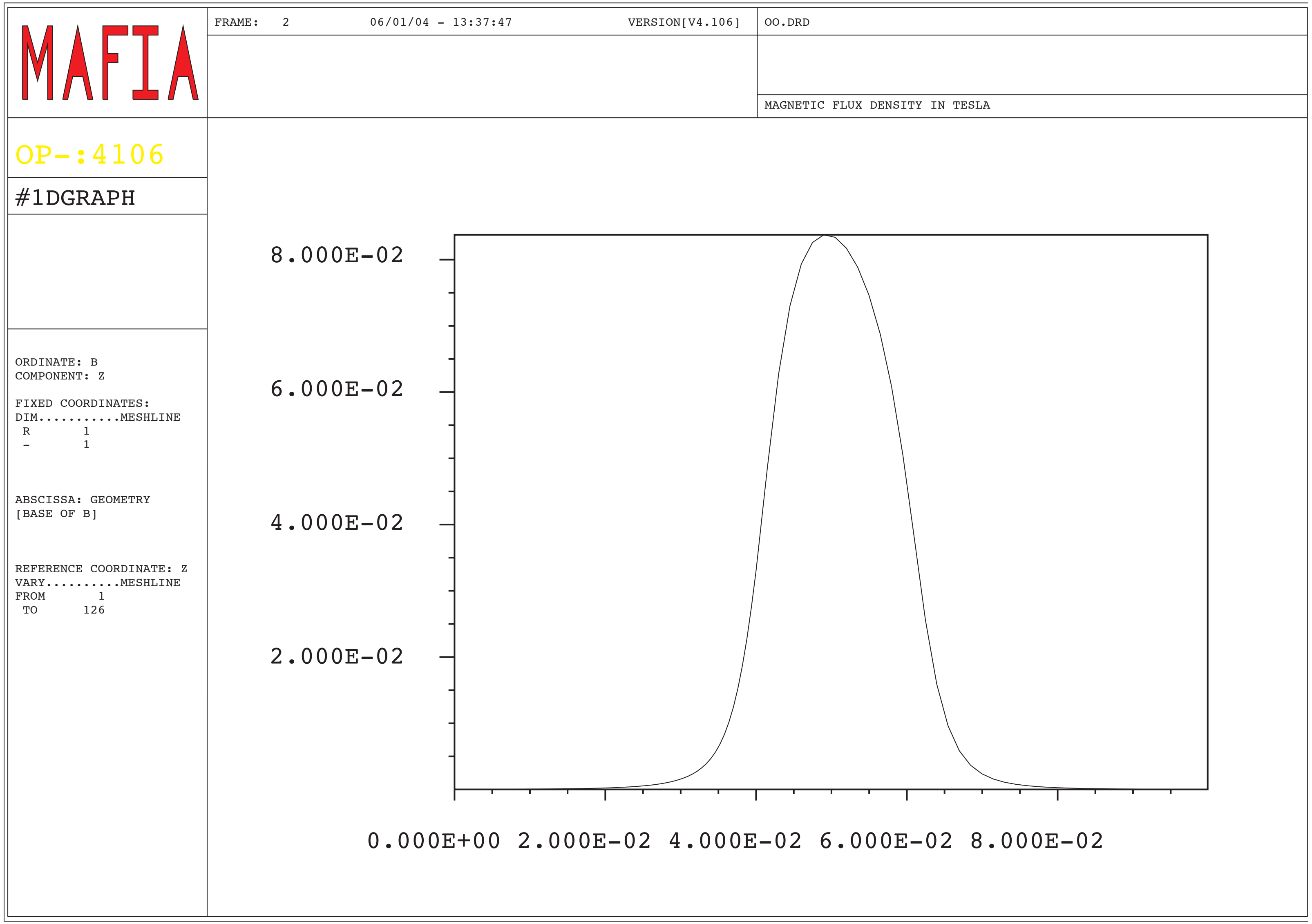
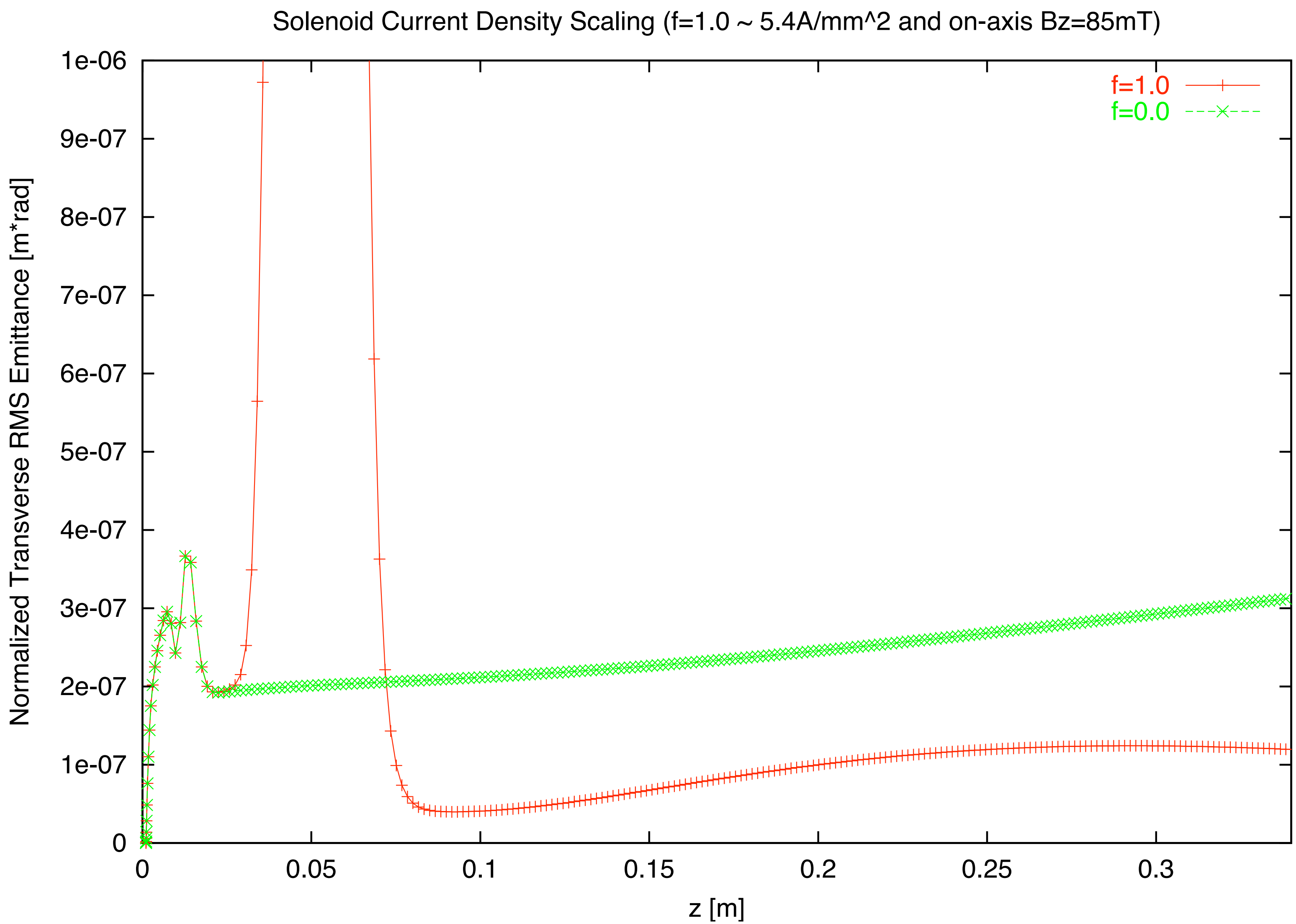
Applying a Solenoid Field (1)



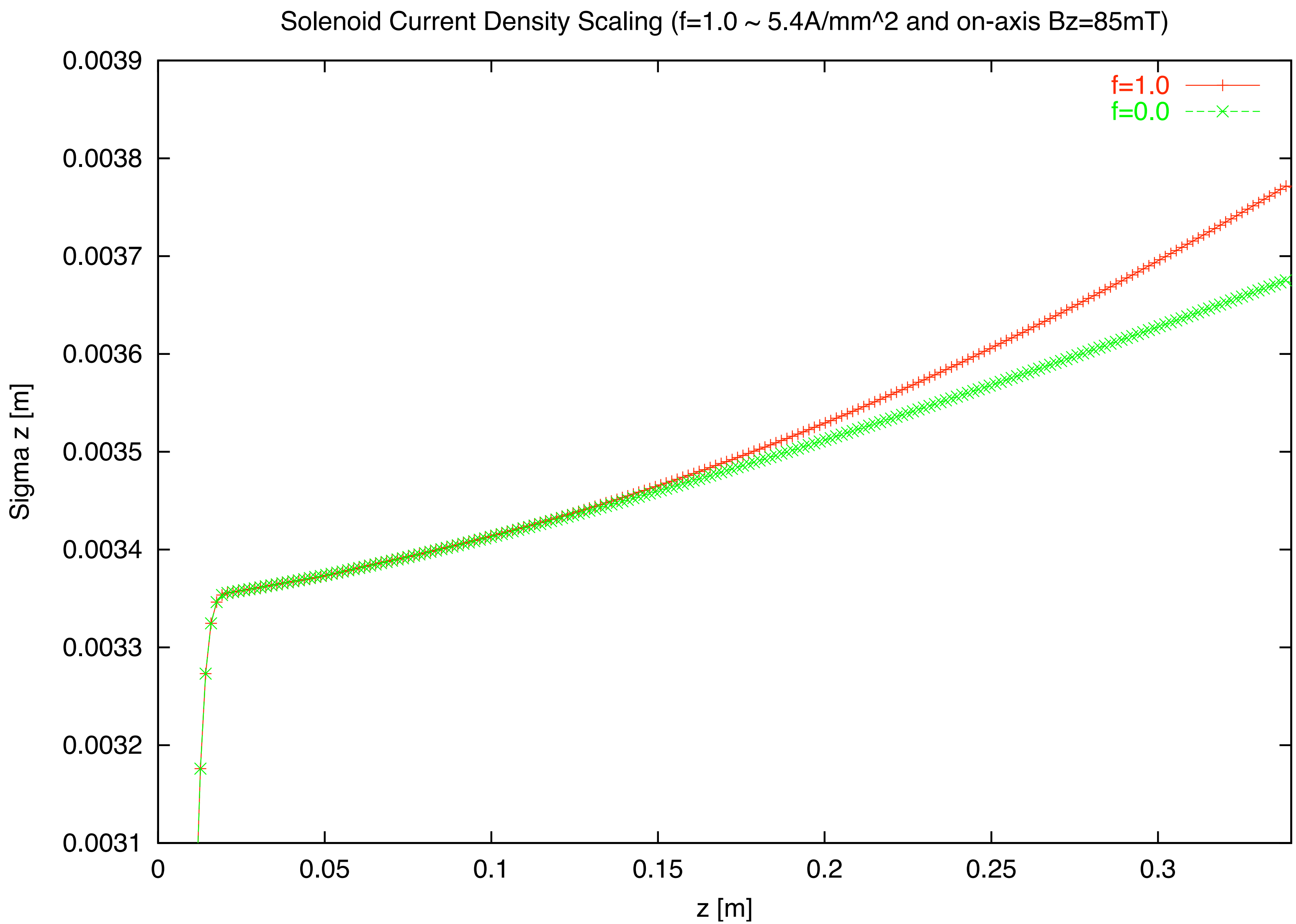
Applying a Solenoid Field (2)



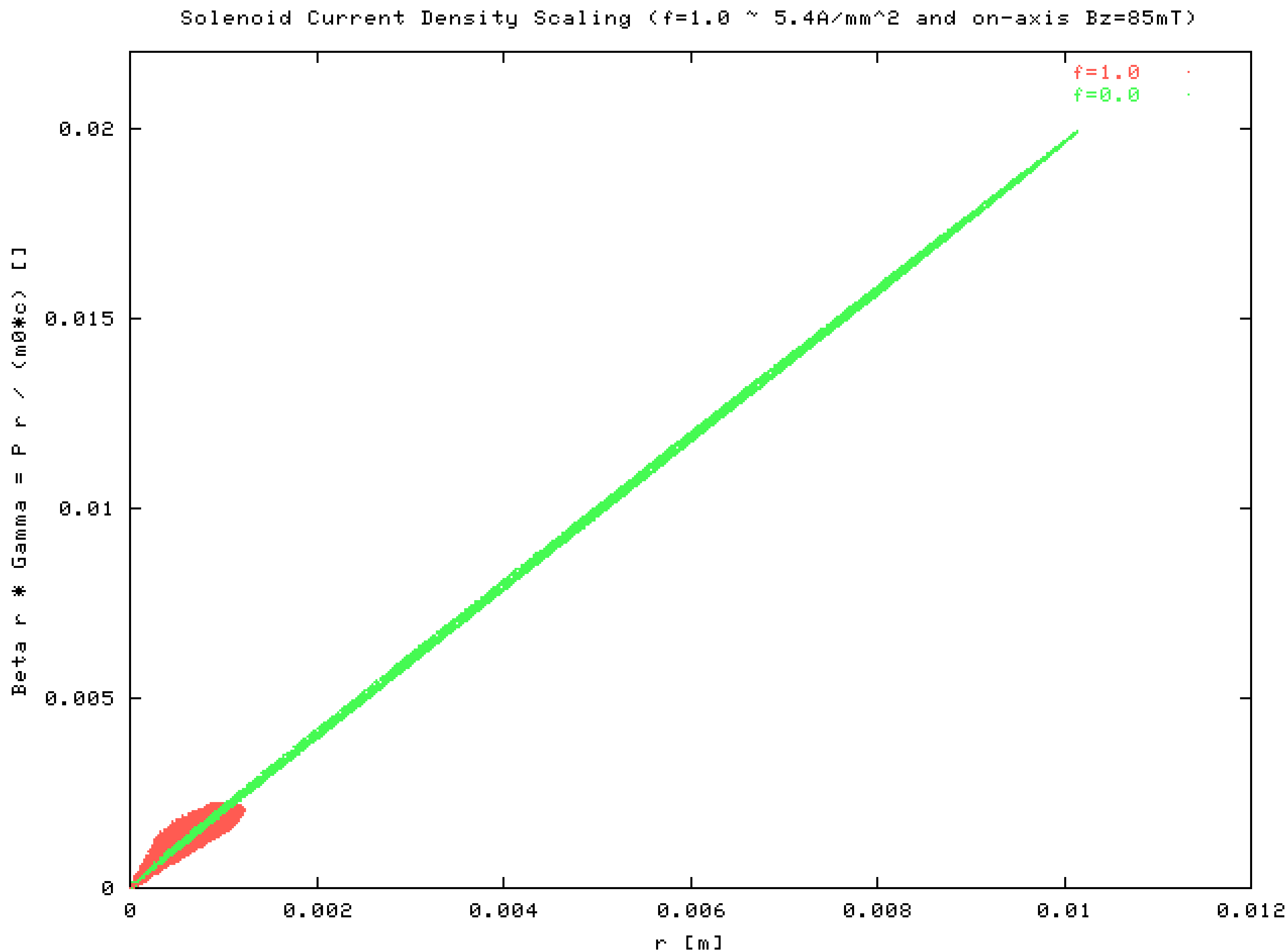
Applying a Solenoid Field (3)



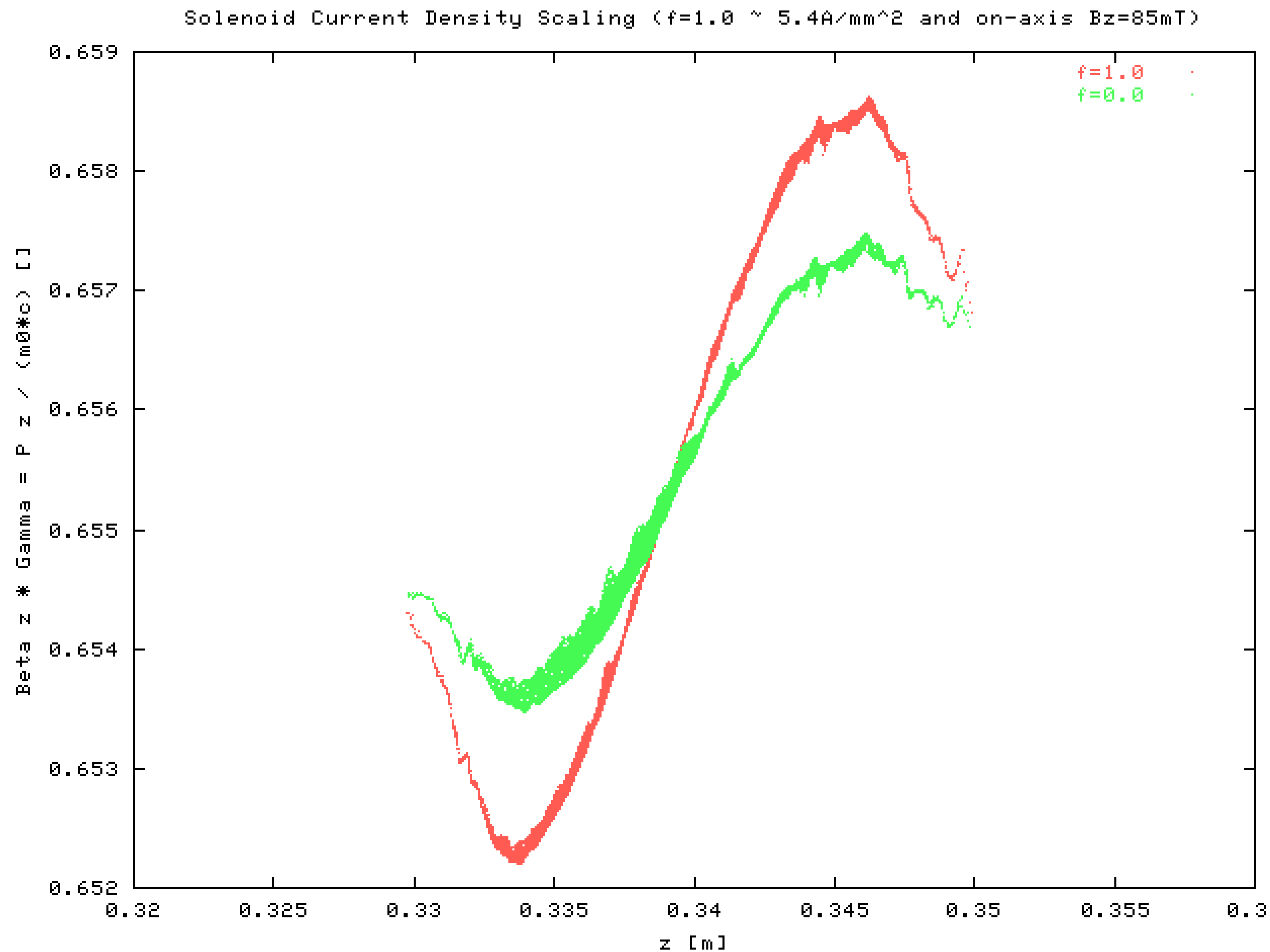
Applying a Solenoid Field (4)



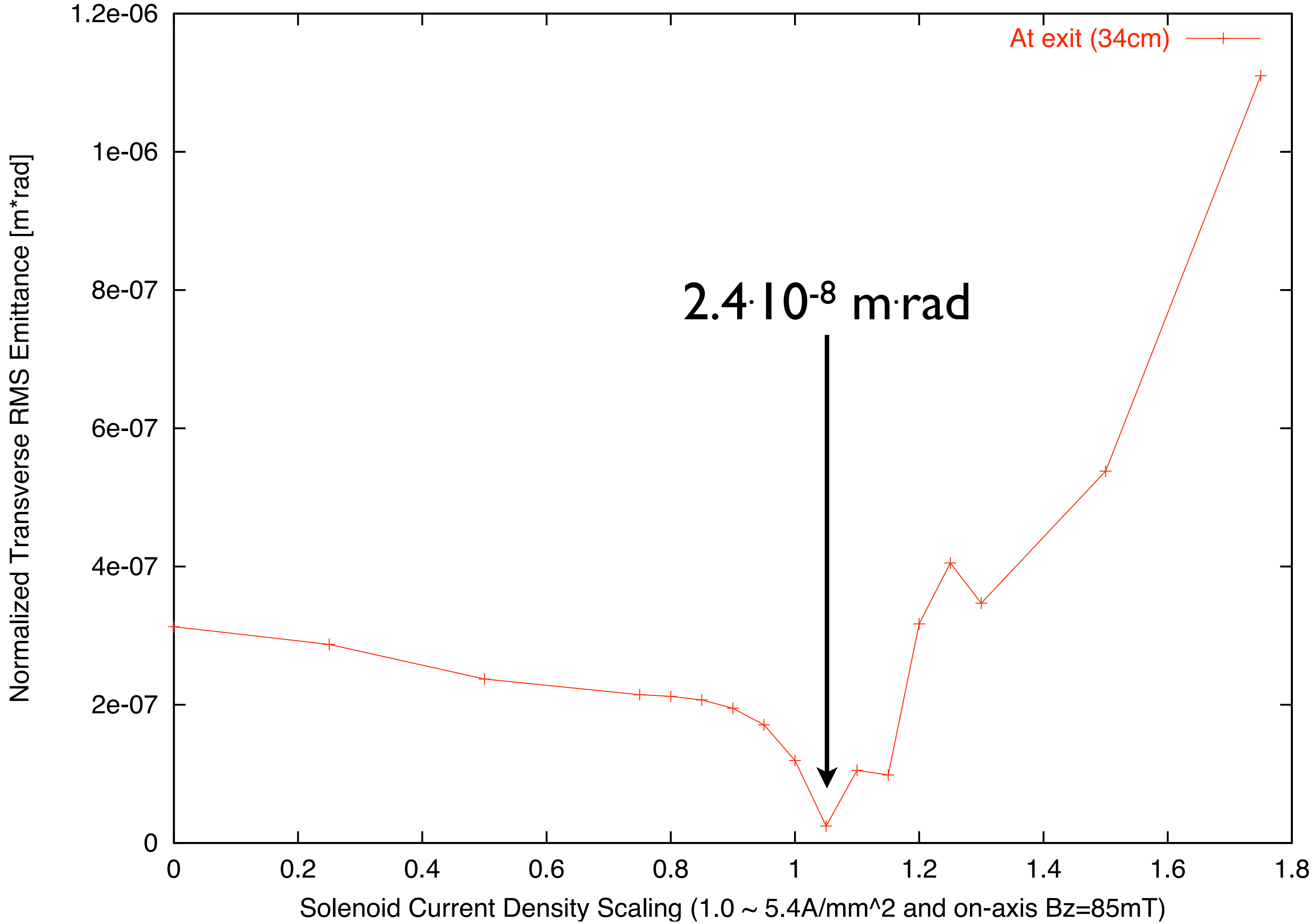
Applying a Solenoid Field (5)



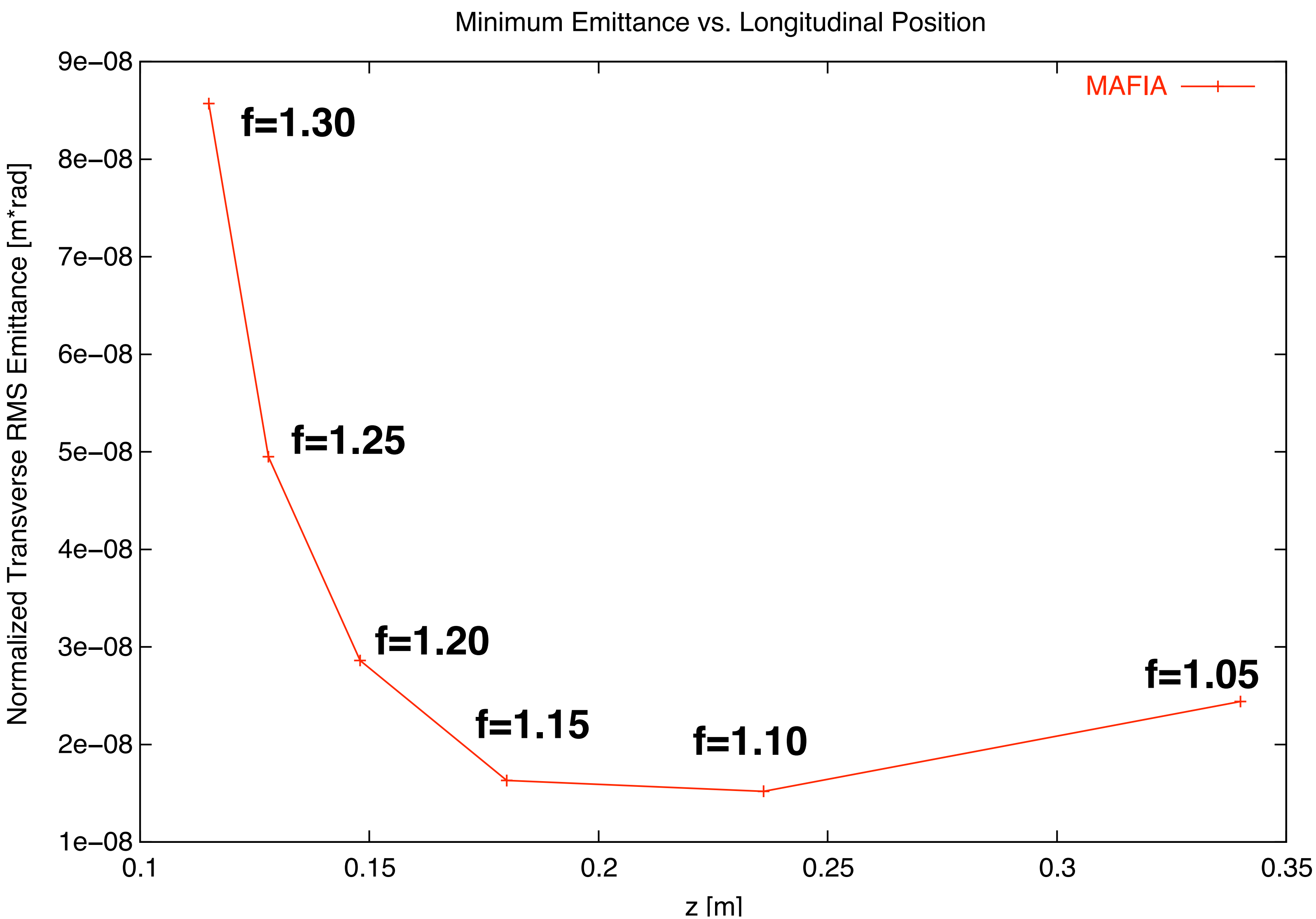
Applying a Solenoid Field (6)



Applying a Solenoid Field (7)



Applying a Solenoid Field (8)



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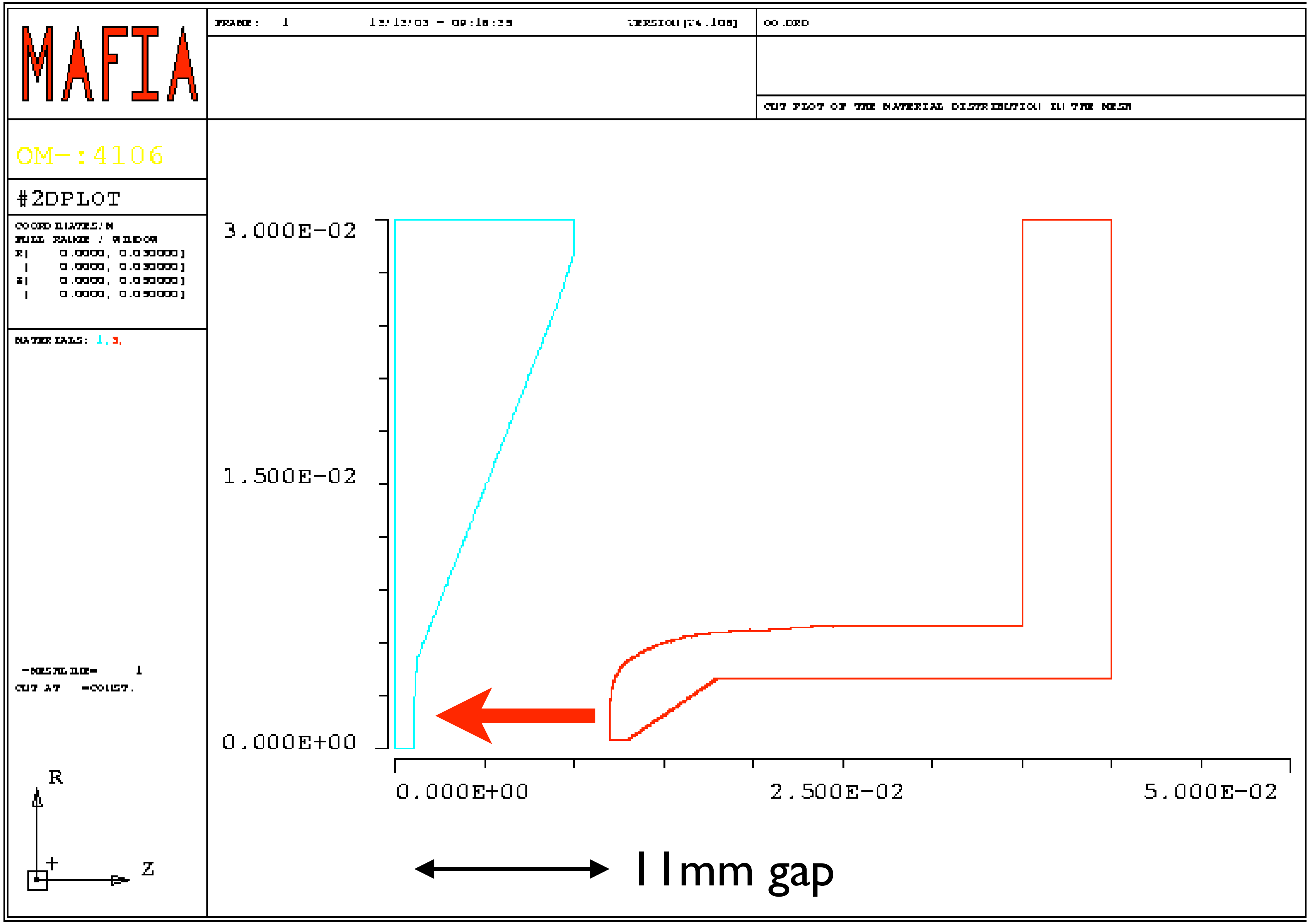
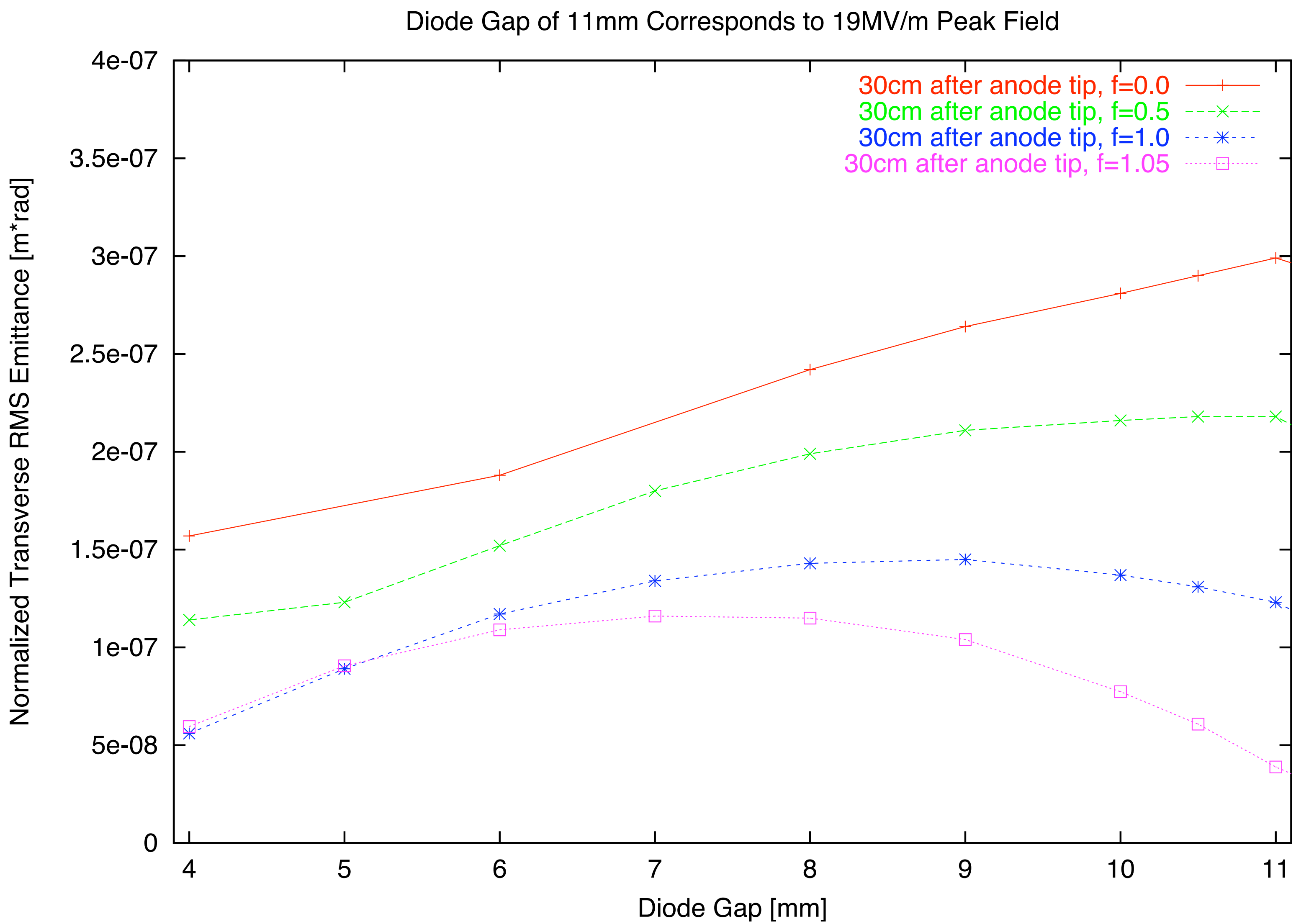
Varying the Gap (I)



Varying the Gap (2)



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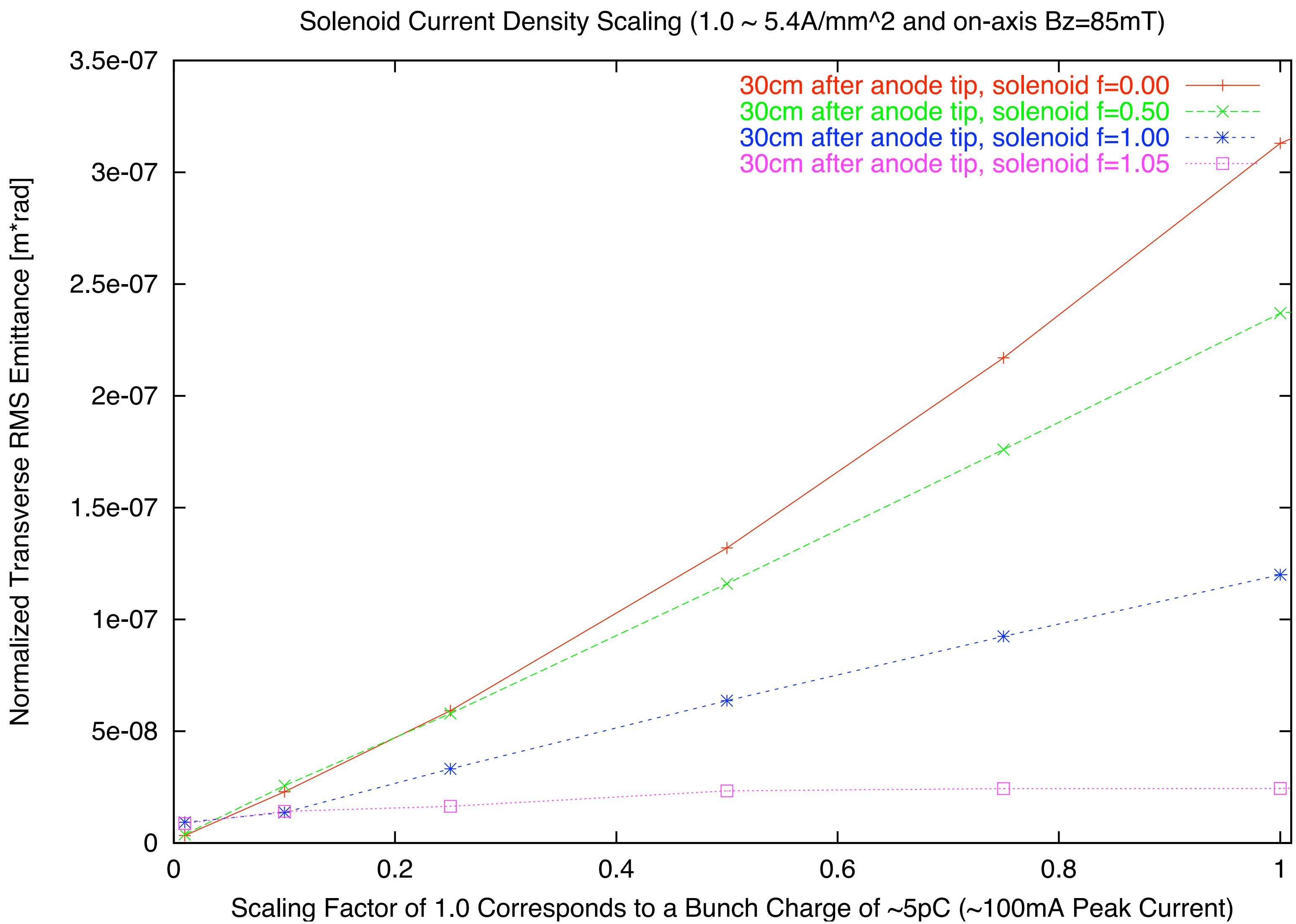
Varying the Bunch Charge



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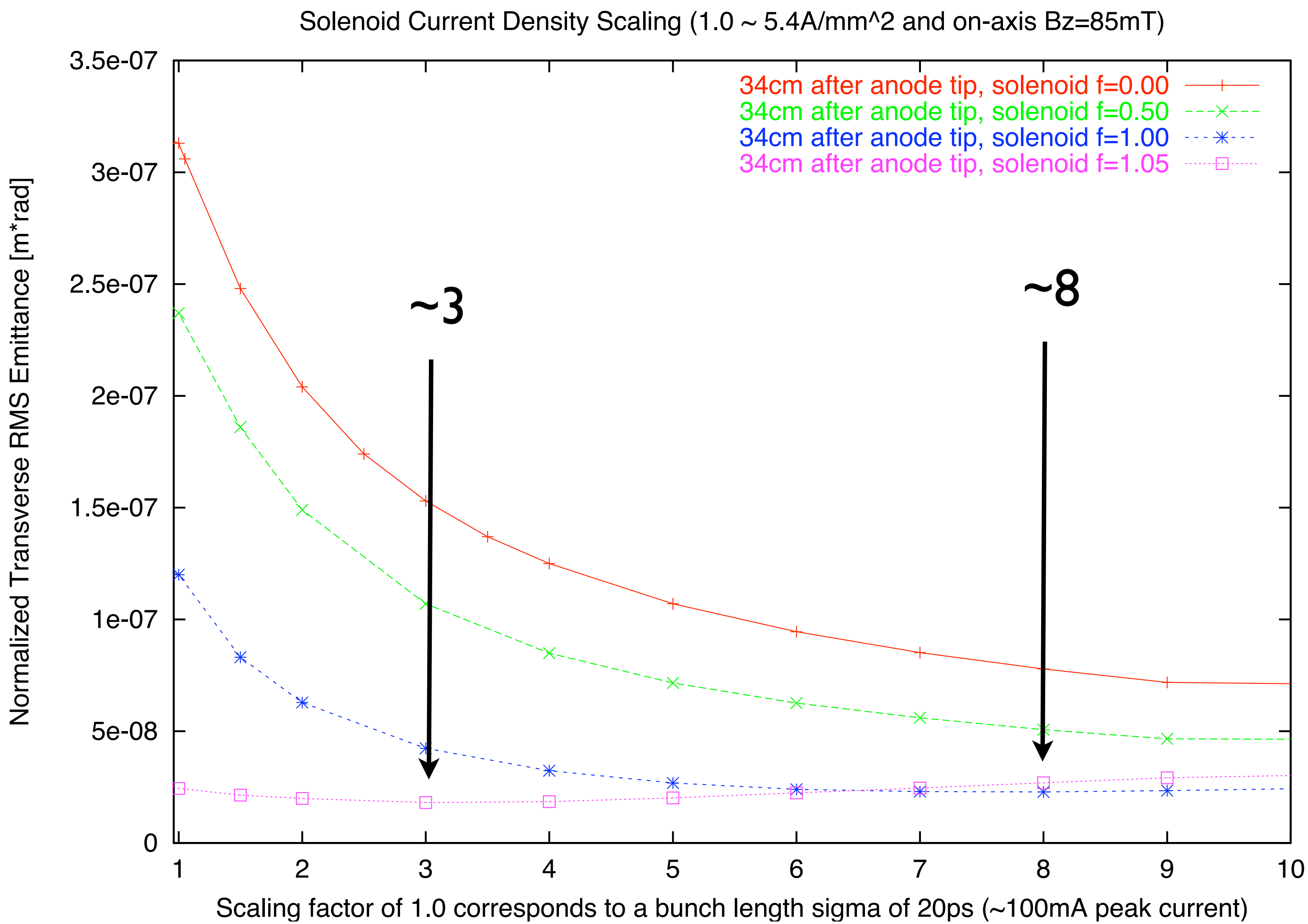
Varying the Bunch Length



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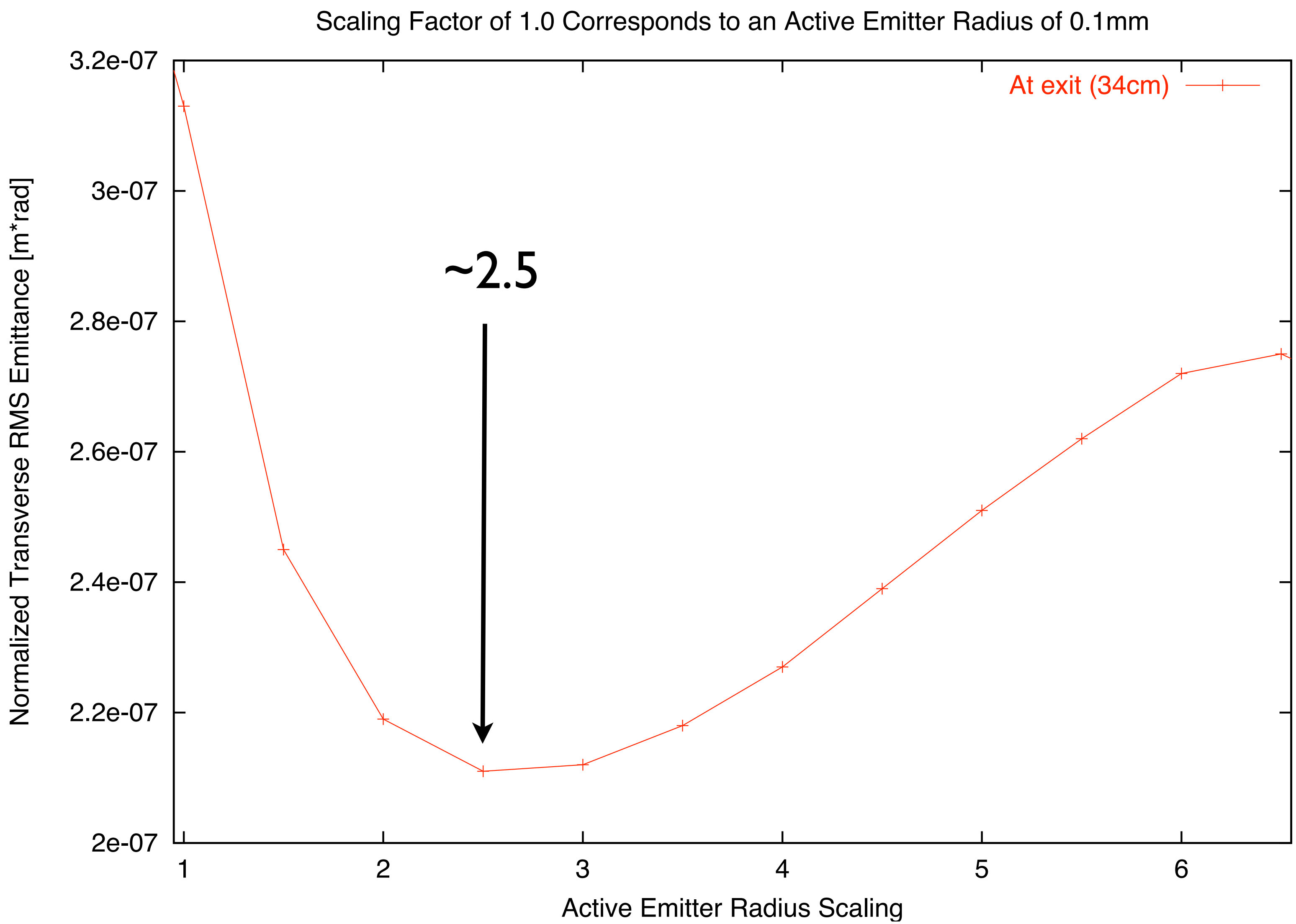
Varying the Active Emitter Radius



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Scaling Parameters - Extrapolating Results

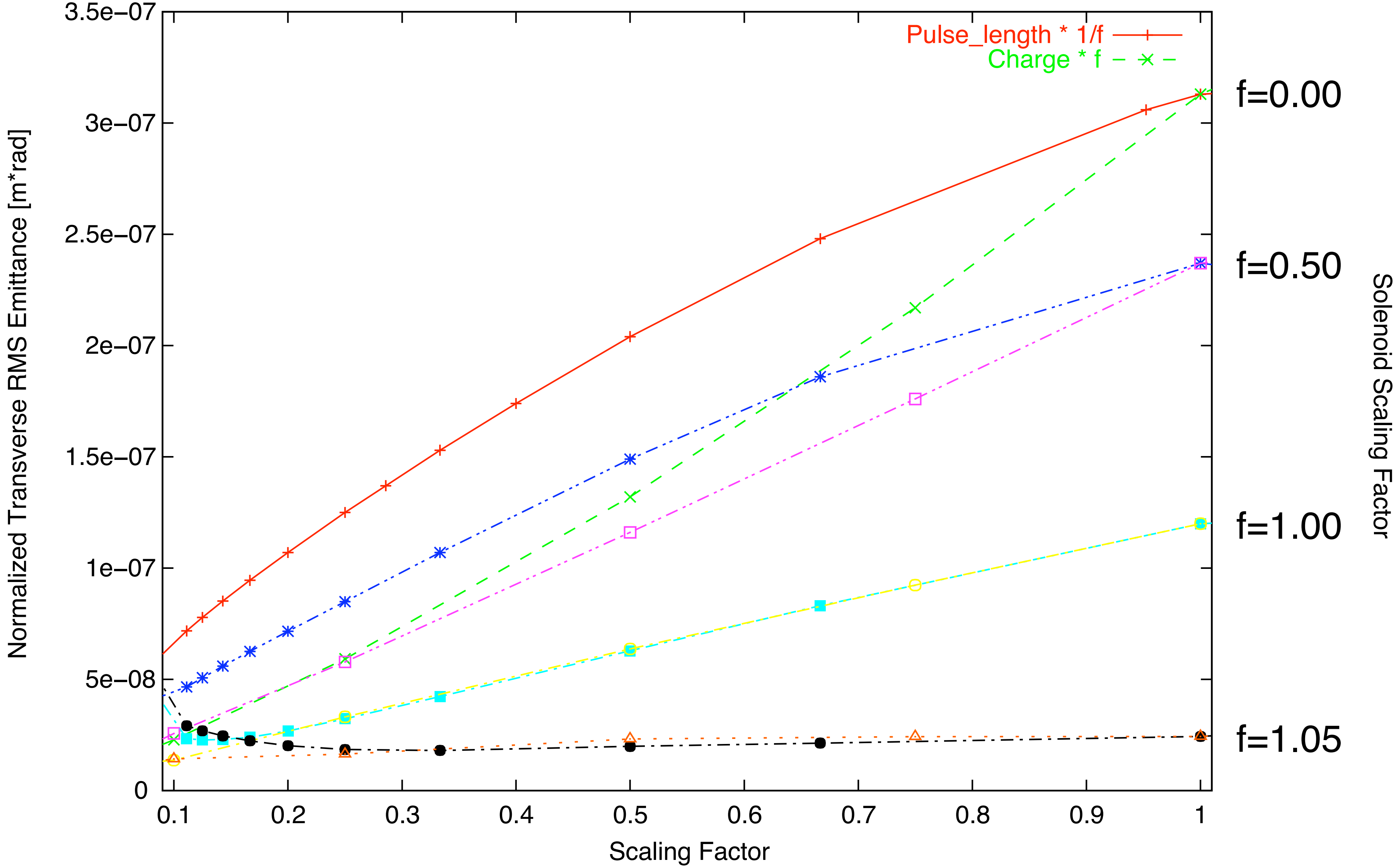
The bare (but ugly) truth:

- The simulated bunch length ($\pm 3\sigma_z$, σ_z=20ps) is much lower than what we expect at the test stand
- However, it is necessary in order to observe the dynamics of the full bunch (MAFIA dumps phase space data at certain times, not at a certain location)

A possible solution:

» Can we simulate long bunches by inserting less charge into short bunches?

Bunch Lengthening vs. Reducing the Charge



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What is Slice Emittance?

Transverse Normalized RMS Emittance

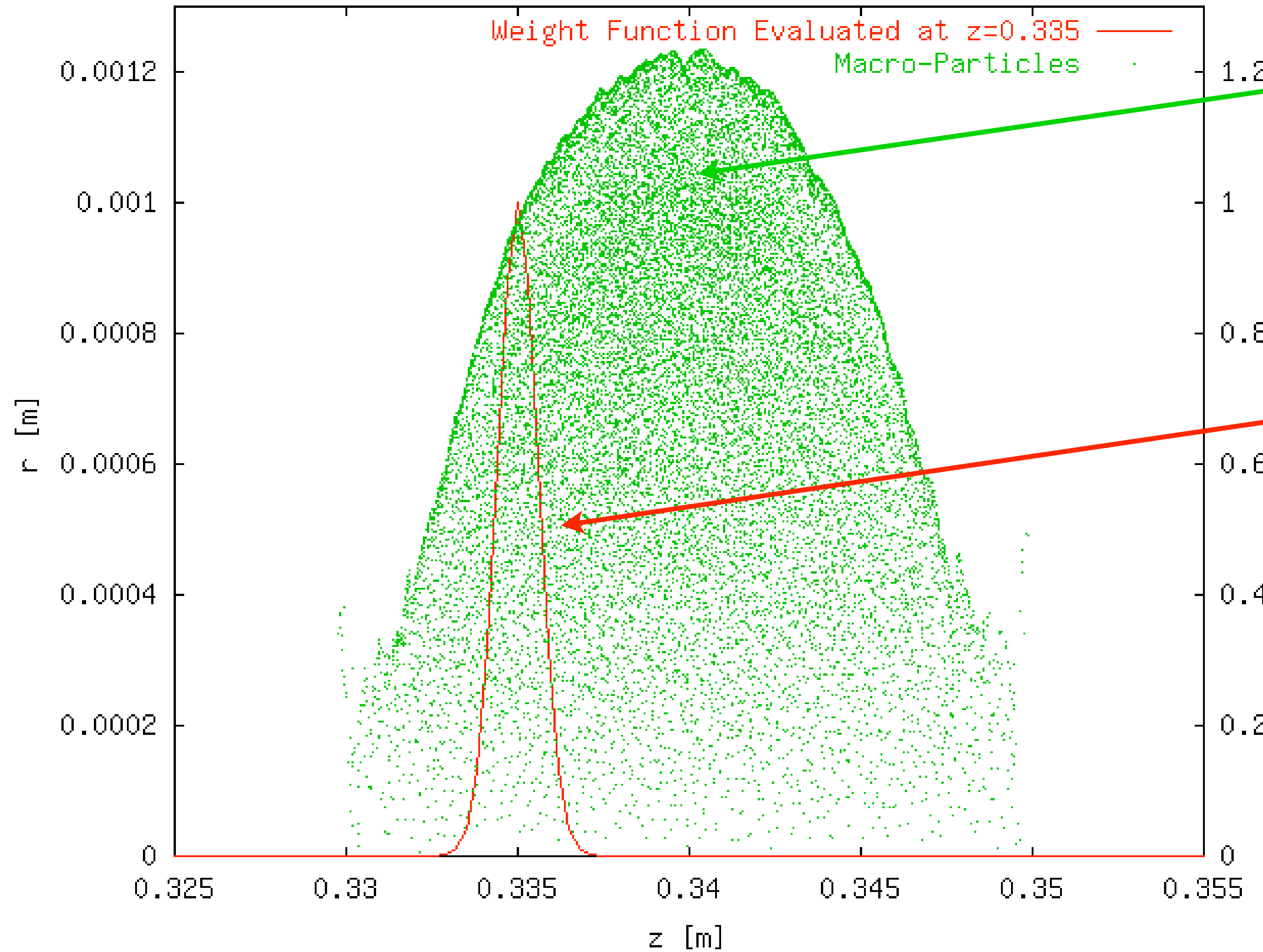
- Projected Emittance (property of one entire bunch)

$$\varepsilon = \sqrt{\langle r^2 \rangle \langle {p_r}^2 \rangle - \langle r p_r \rangle^2} \simeq \gamma\beta \sqrt{\langle r^2 \rangle \langle r'^2 \rangle - \langle r r' \rangle^2}$$

- Slice Emittance (depends on the location t_0 of the slice within the bunch and the width σ_t of the slice)

$$\varepsilon_{t_0} = \gamma\beta \sqrt{\langle r_{t_0}^2 \rangle \langle {r'_{t_0}}^2 \rangle - \langle r_{t_0} \, r'_{t_0} \rangle^2}$$

How do we calculate Slice Emittance?

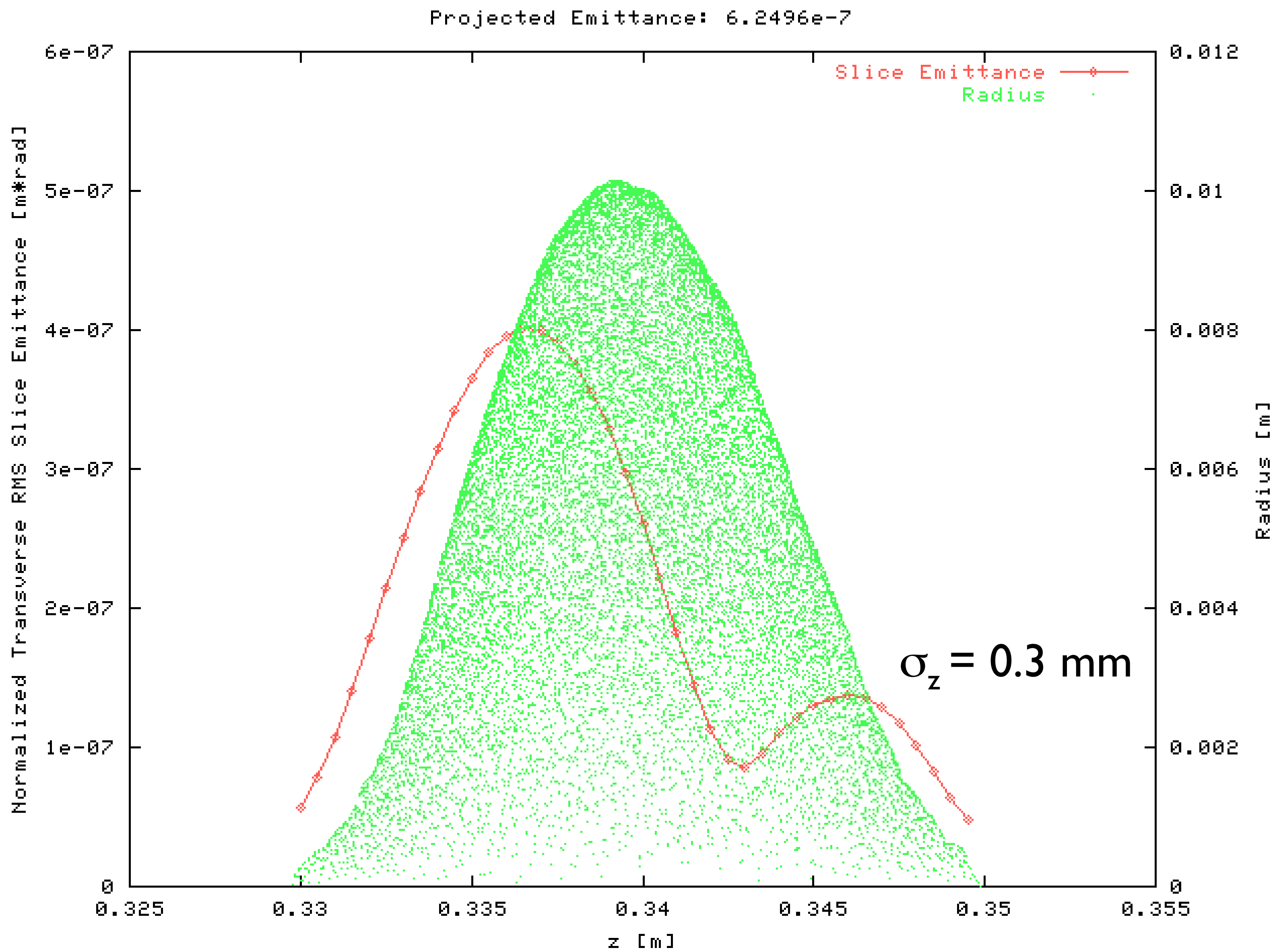


$$\langle r_{t_0}^2 \rangle = \frac{1}{W_0} \sum_{i=1}^{N} {r_i}^2 \cdot w_{i,0}$$

$$w_{i,0} = e^{-\frac{(t_i - t_0)^2}{2\sigma^2}} = e^{-\frac{(z_i - z_0)^2}{2\beta^2 c^2 \sigma^2}}$$

$$W_0 = \sum_{i=1}^{N} w_{i,0}$$

Slice Emittance Example



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Conclusions (1)

Gun Design:

- We're able to maintain a peak electric field strength < 20 MV/m
- By choosing a proper cathode electrode tilt angle we've managed to reduce the norm. transv. emittance to $6 \cdot 10^{-8}$ m·rad
- By closing the gap between the electrodes the emittance can be further minimized to levels well below 10^{-8} m·rad
  - » How far will material and vacuum conditions allow us to go?

Solenoid:

- Using a properly tuned solenoid the emittance can be minimized at a certain location of interest
- Currently the minimum achieved norm. transv. emittance at the exit of the structure (z = 34 cm) is $2.4 \cdot 10^{-8}$ m·rad

Conclusions (2)

Bunch Charge:

- The amount of charge inserted into the bunch scales the emittance roughly linear if we have properly tuned solenoid focussing

Bunch Length:

- Without solenoid focussing lengthening the bunch leads to lower emittance
- With solenoid focussing there is a bunch length that minimizes emittance

Active Emitter Area:

- For a given anode iris radius there is an optimum active emitter radius
- For a given FEA the ratio of active emitter radius and anode iris radius can be optimized for minimum emittance

Conclusions (3)

Extrapolating Results:

- In general we can not extrapolate exact results for longer bunches, but we can estimate upper limits for ε
- This has to do with the fact that our bunches are neither disk-shaped nor cigar-shaped, but rather between these two limits where the space charge forces depend strongly on the bunch geometry (ratio between bunch length and radial bunch envelope)

Slice Emittance:

- We can calculate slice emittance values for a bunch and compare with the projected emittance, but parameters have to be properly chosen due to the trade-off between numerical noise and possible resolution
- As expected the slice emittance in the center of the bunch is much smaller than the projected emittance of the entire bunch