In-line MRI-linac Configuration

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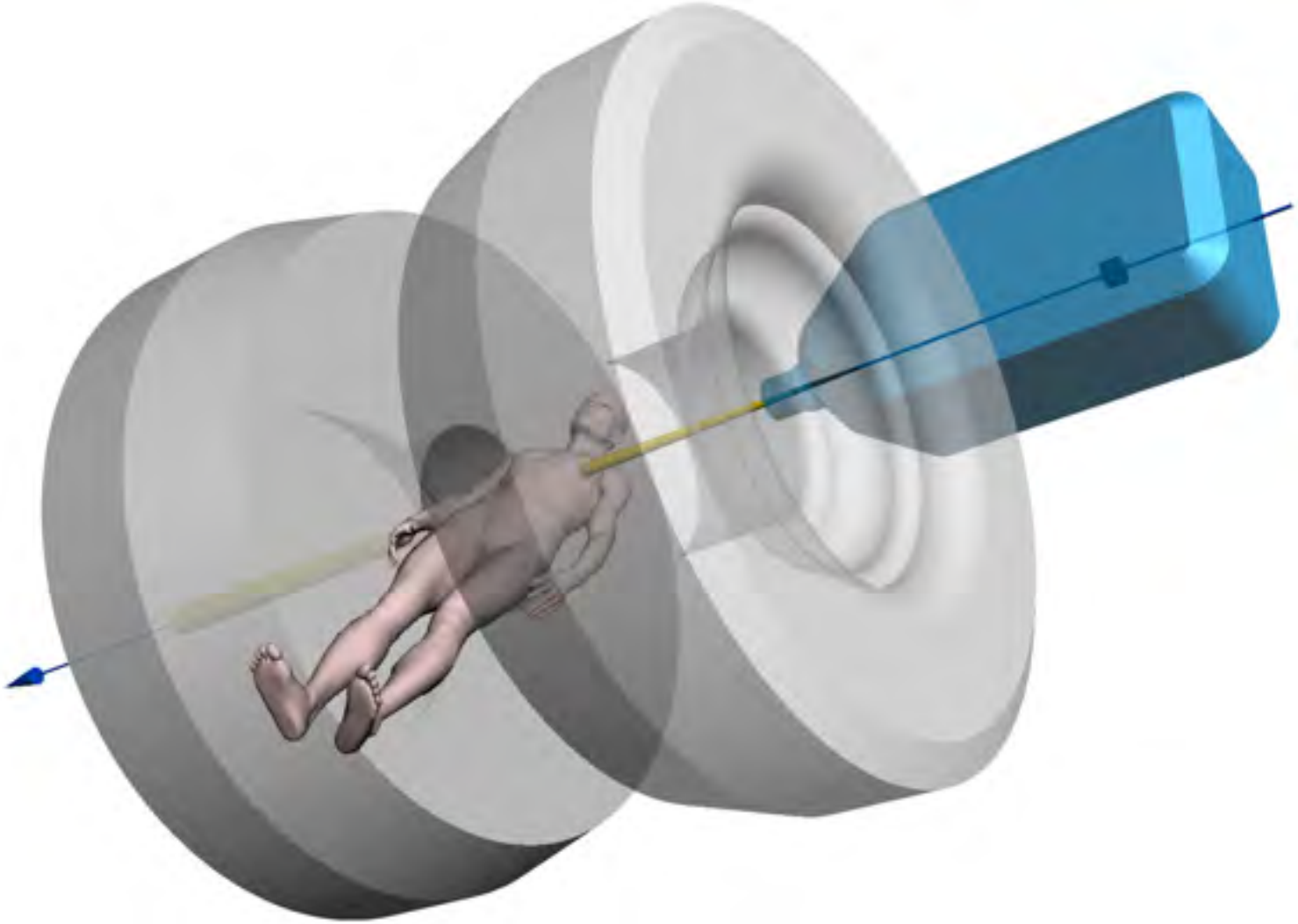
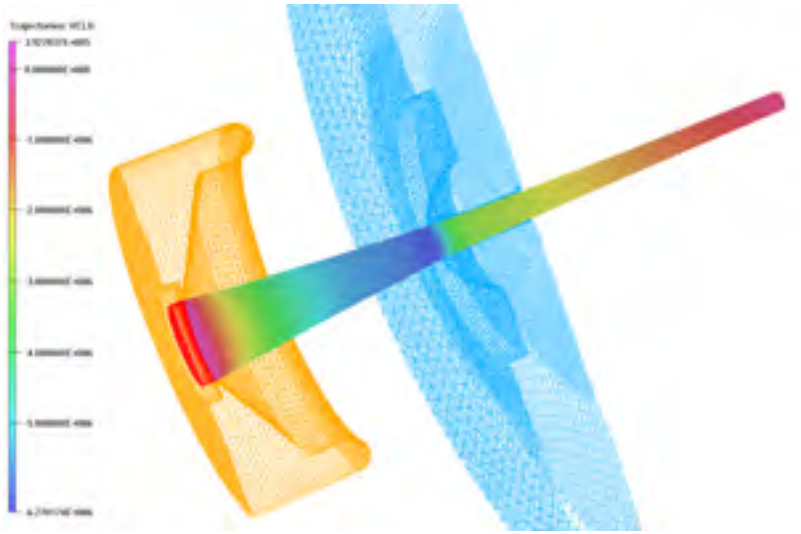


SOURCE: D. Constantin et al., *Med. Phys.*, **38**:4174-4185, 2011

Methods and Materials

0.5T GE Signa SP (mrT) - Side View

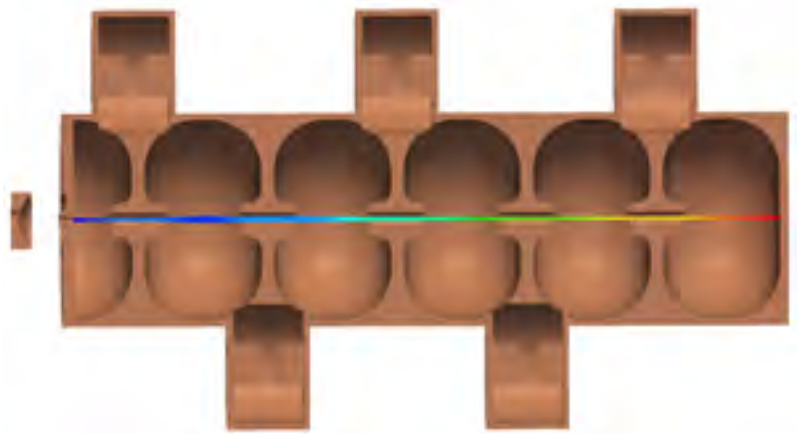
Electron Gun Model with Solution (0T)



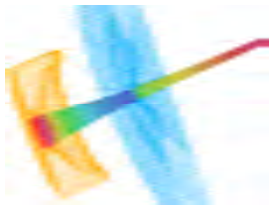
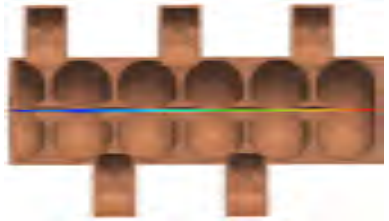
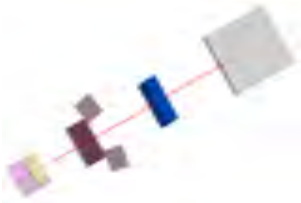
References:

- Magnetic Field: Constantin & al., *Med. Phys.*, **38**:4174-4185, 2011
- Electron Gun: St. Aubin & al., *Med. Phys.*, **37**:2279-2288, 2010
- Waveguide: St. Aubin & al., *Med. Phys.*, **37**:466-476, 2010
- Software: Scala, COMSOL, SuperFish, Parmela, Matlab, Python

Varian 600C Waveguide Model (0.13T)



Simulation Model

COMSOL Multiphysics: MRI magnet fringe field

SCALA: space charge simulation

PARMELA: beam transport

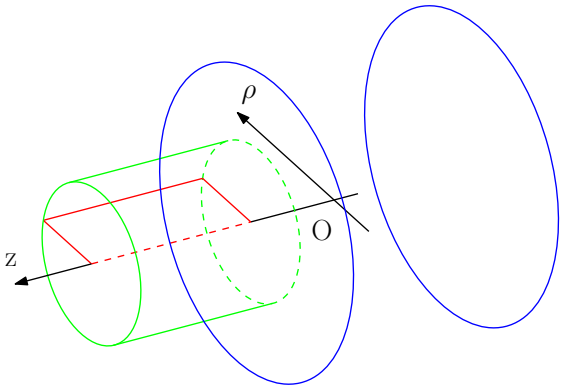
Geant4: radiation simulation

COMSOL: RF fields

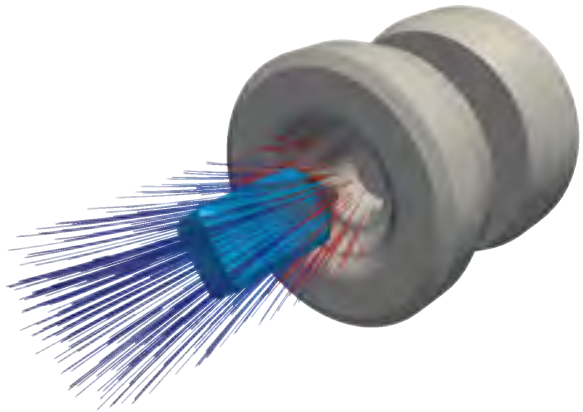
MATLAB, Python, FORTRAN, C++, Bash: data sharing and post-processing

GE Signa SP (mrT) MRI Scanner - Magnetic Fringe Field

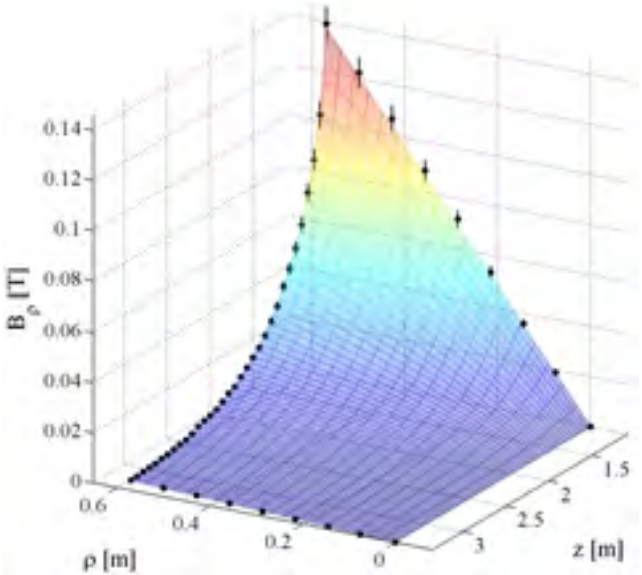
mrT Scanner - Sketch



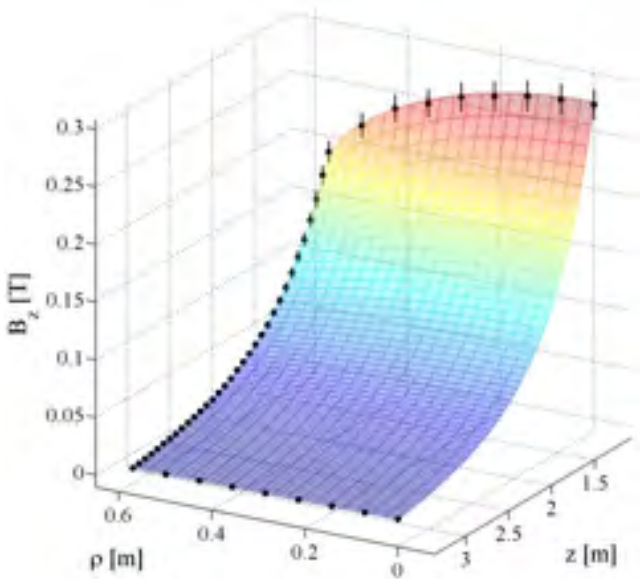
mrT Scanner Model with Field Lines



mrT Fringe Field - Radial Component



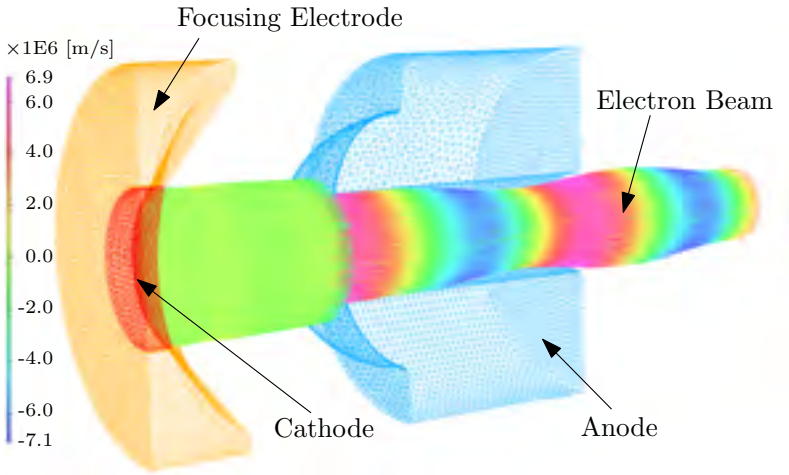
mrT Fringe Field - Axial Component



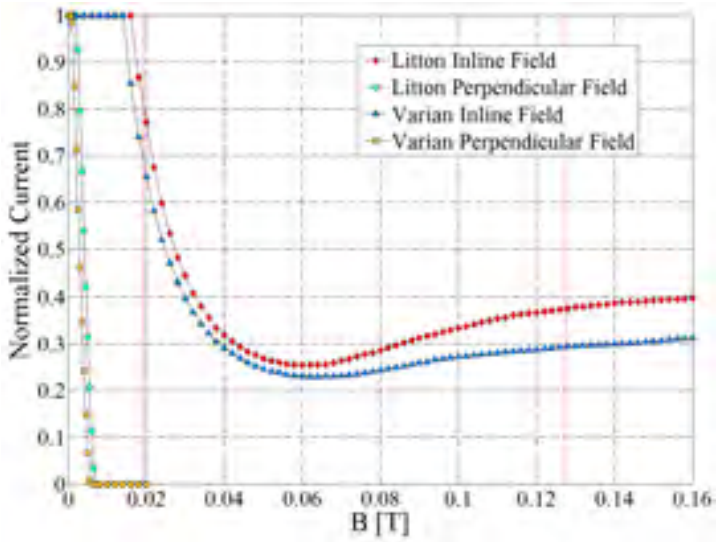
$$\gamma m_0 r^2 \dot{\theta} + \frac{e_0}{2\pi}\Phi_B = \text{const}$$ (Bush Theorem)

- The particle trajectory is a helix along the field lines
- An electron beam is magnetically confined close to the axis of symmetry of the system
- As the field increases the radius of confinement decreases

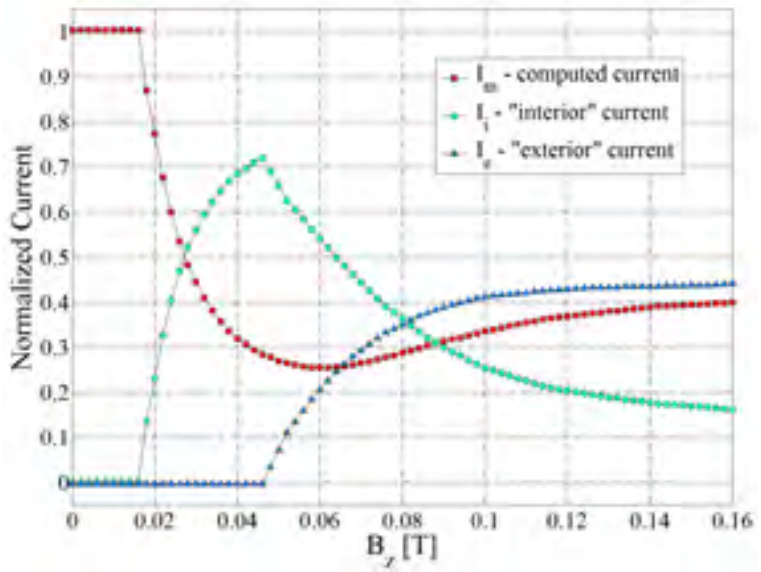
Litton L-2087 Solution at $B_z = 0.16$T



Current dependence on magnetic field



Anode Currents



SOURCE: Constantin & al., *Med. Phys.*, **38**:4174-4185, 2011

Cathode characteristics

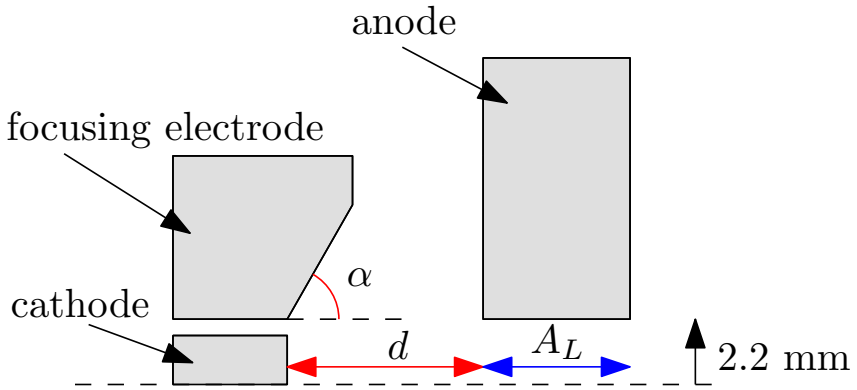
- Type-M ($\phi = 1.8$ eV) with flat surface
- Workload 4A/cm^2 $\Rightarrow$ $R_C = 1.7$mm
- $T = 1189$ K $\Rightarrow$ $I = 0.361$A

Twiss parameters

$\varepsilon_{\rm rms} = 0.4\pi$ mm mrad, $\alpha_{\rm rms} = 4.9$ (0T)

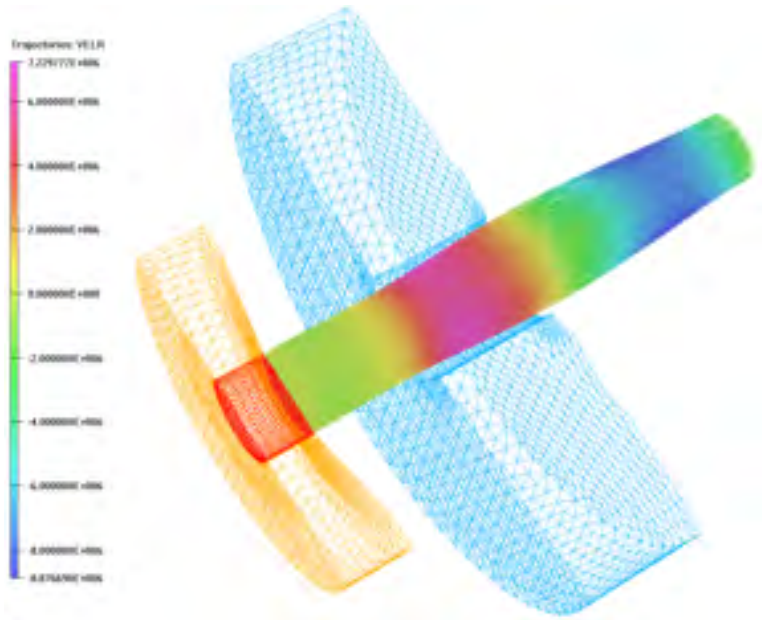
$\varepsilon_{\rm rms} = 0.9\pi$ mm mrad, $\alpha_{\rm rms} = 16.1$ (0.19T)

Optimized geometry for B=0.19T

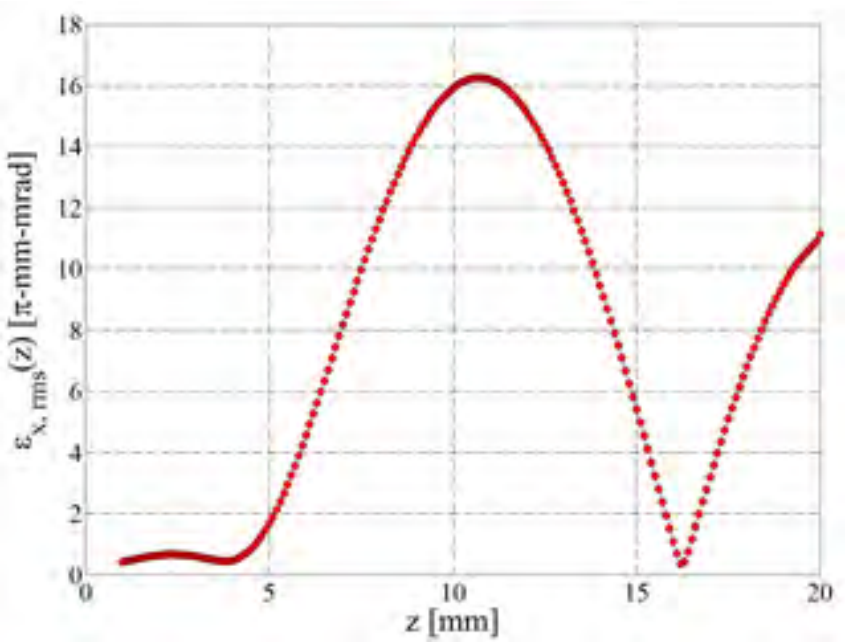


$d = 4\text{mm} - 6\text{mm}$, $\alpha = 80^\circ - 90^\circ$

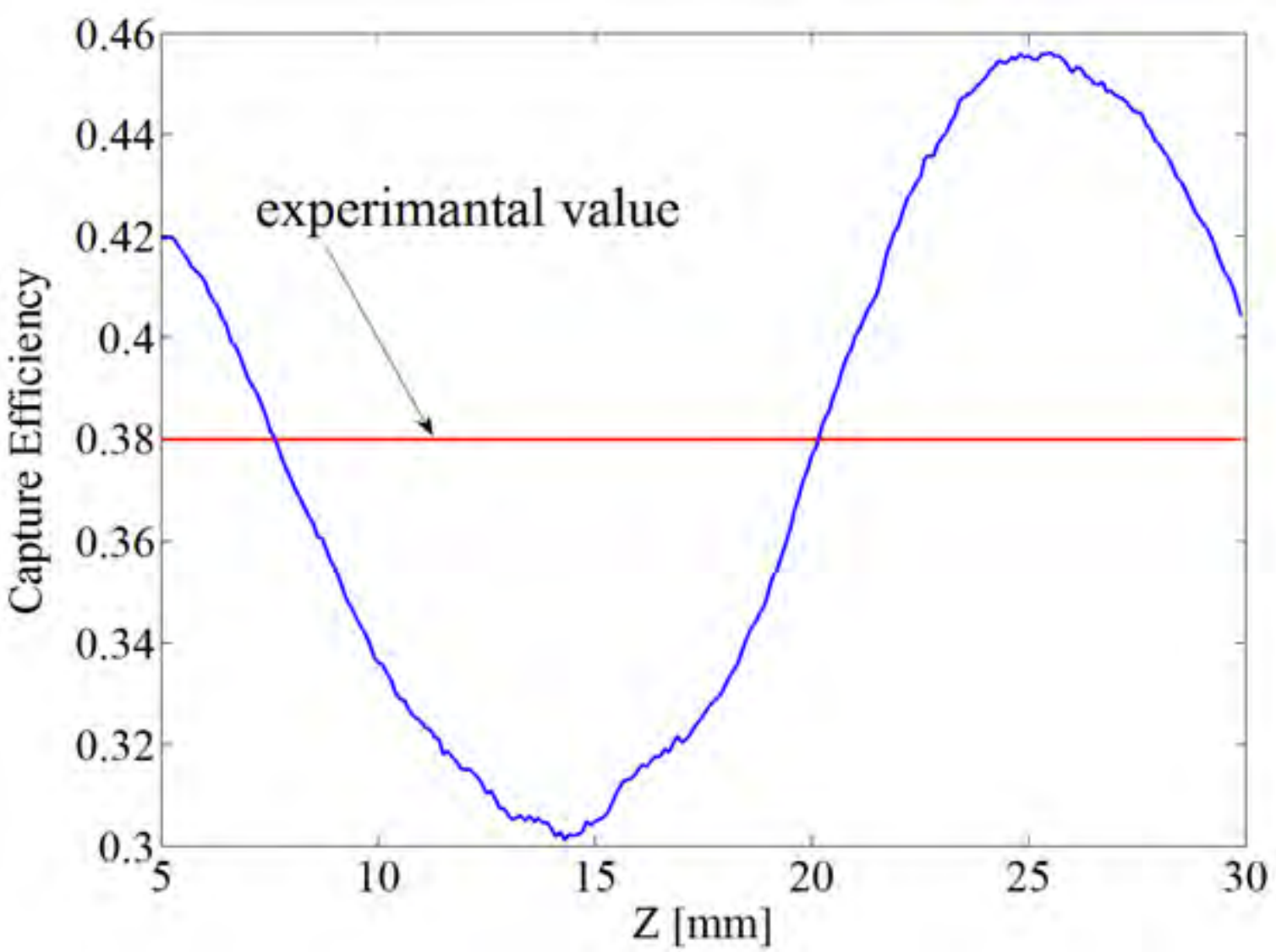
Solution at 0.19T ($\alpha = 85^\circ$, $d = 5$mm)



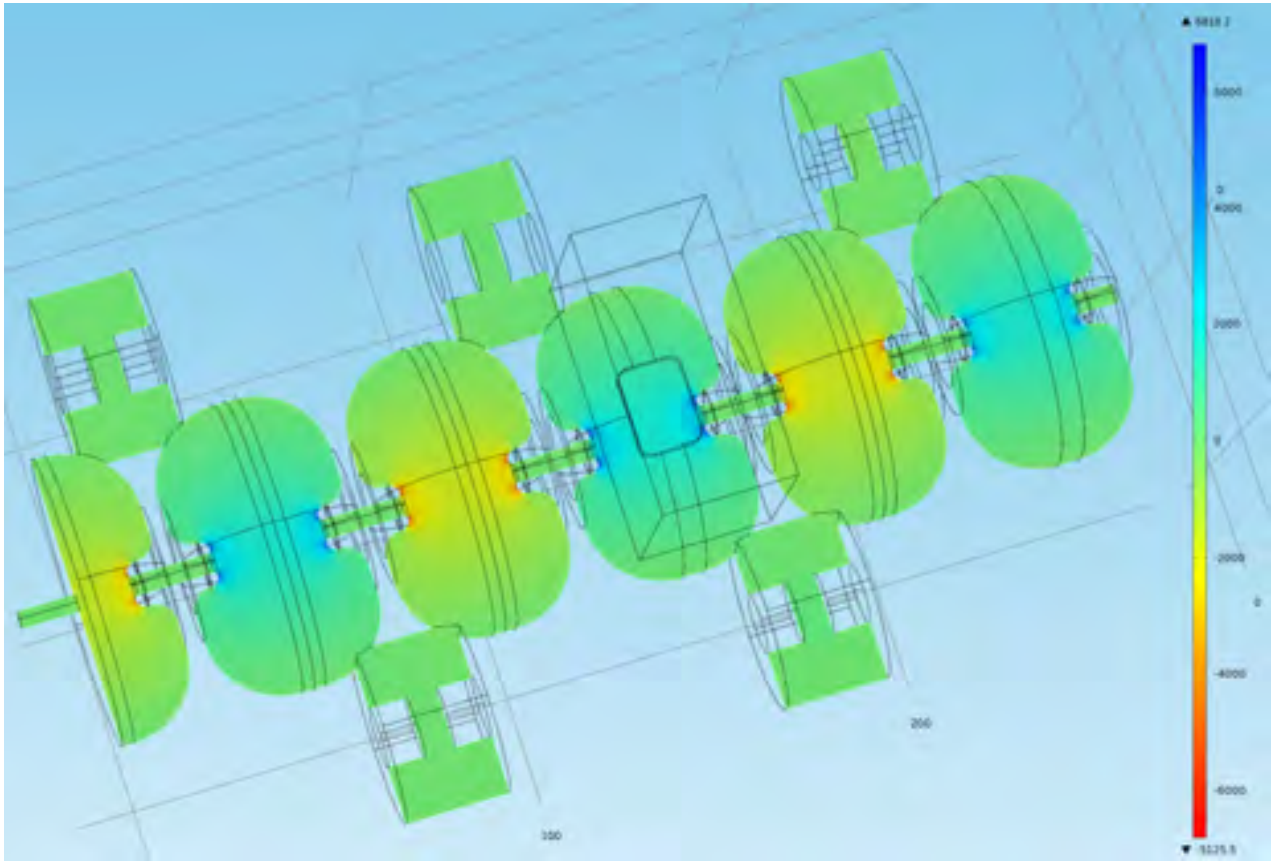
Emittance at 0.19T ($\alpha = 85^\circ$, $d = 5$mm)



Linac Capture Efficiency Dependence on Beam Injection Position



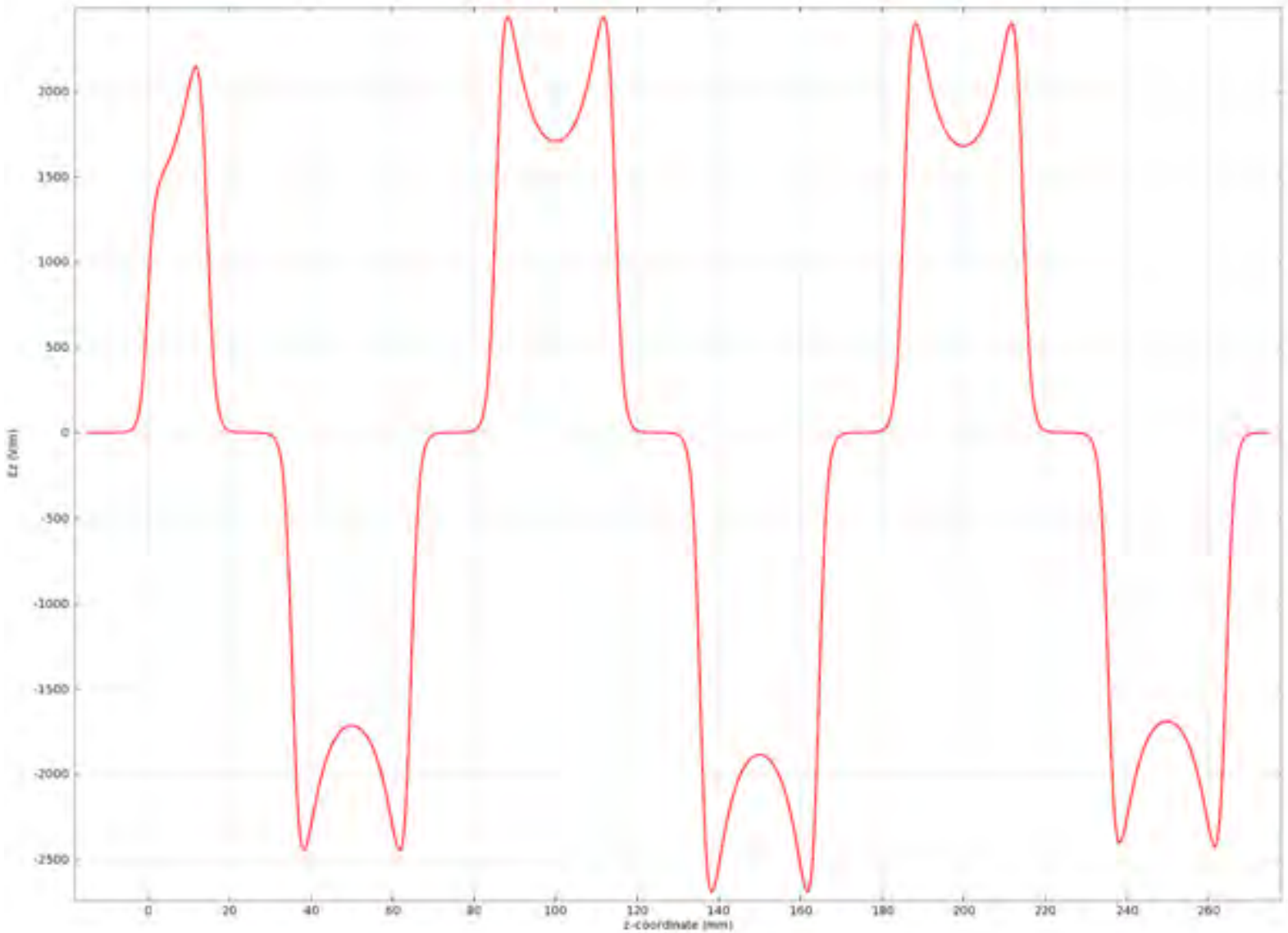
COMSOL - Full Waveguide Solution



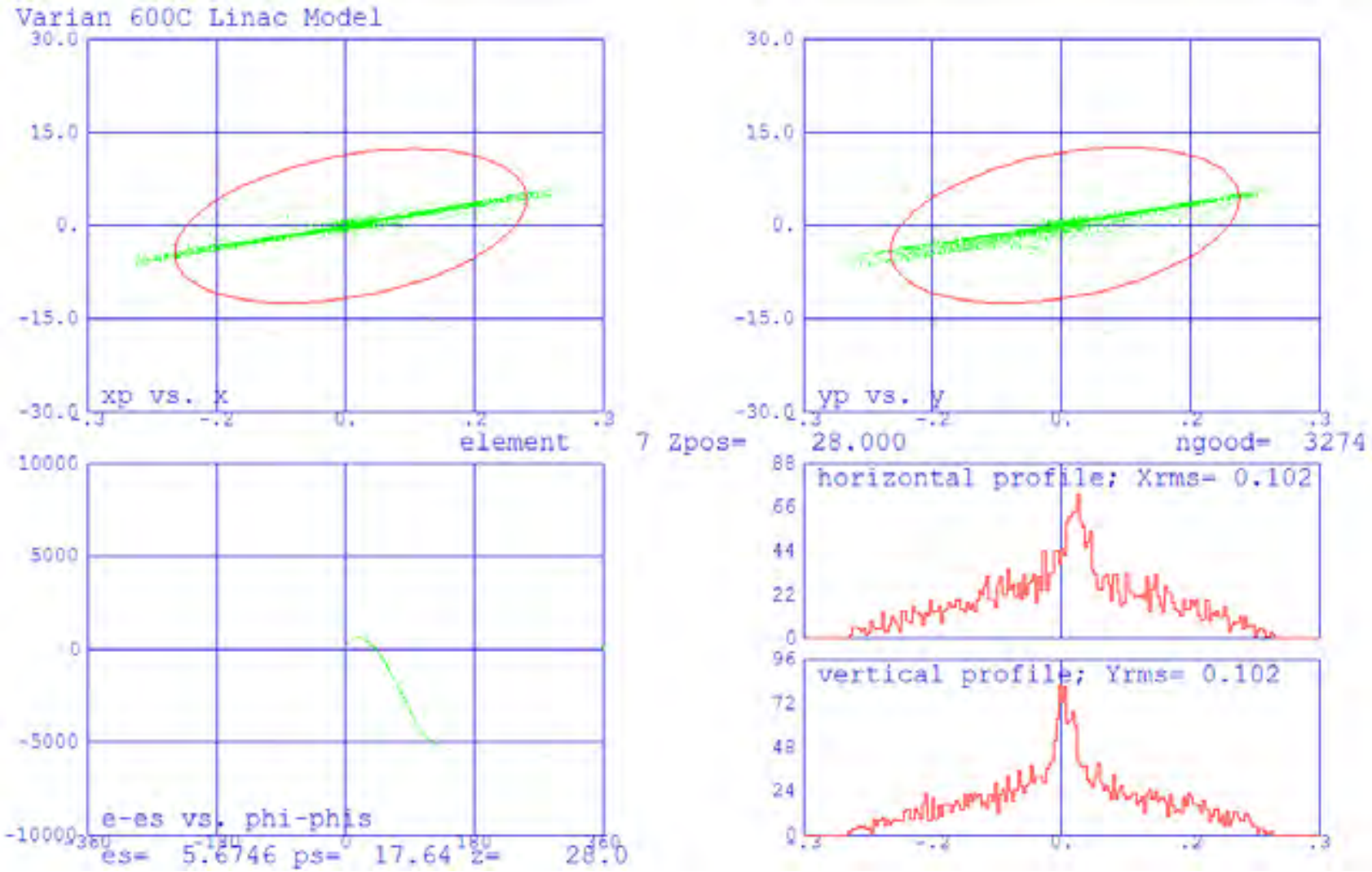
- Finite Elements: 594,772
- DOF: 11,488,251
- Memory: $\sim$ 1.4 TB

- Frequency: 2998.812 MHz
- Solution Time: 8102 s

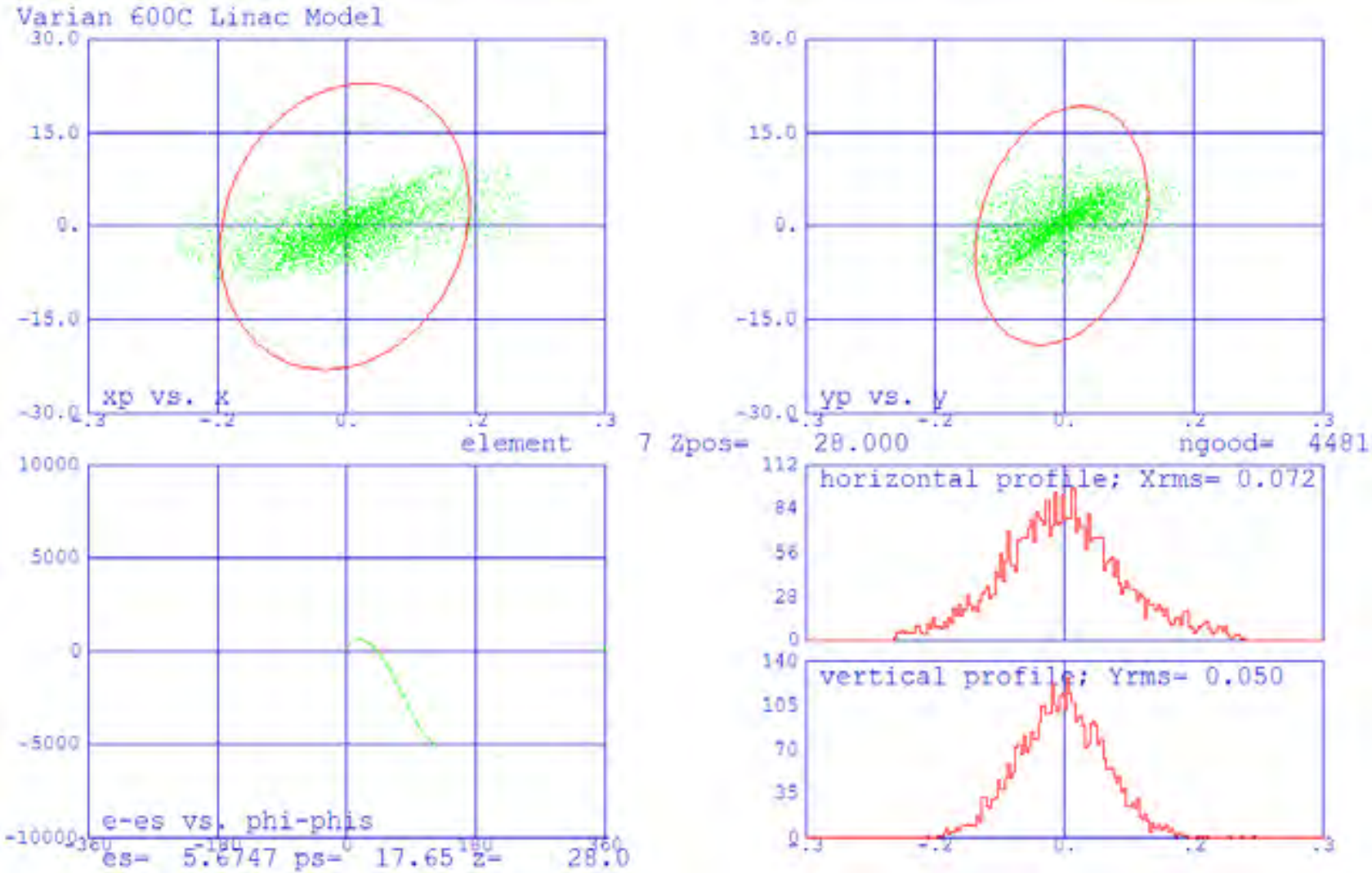
COMSOL - Ez along linac axis



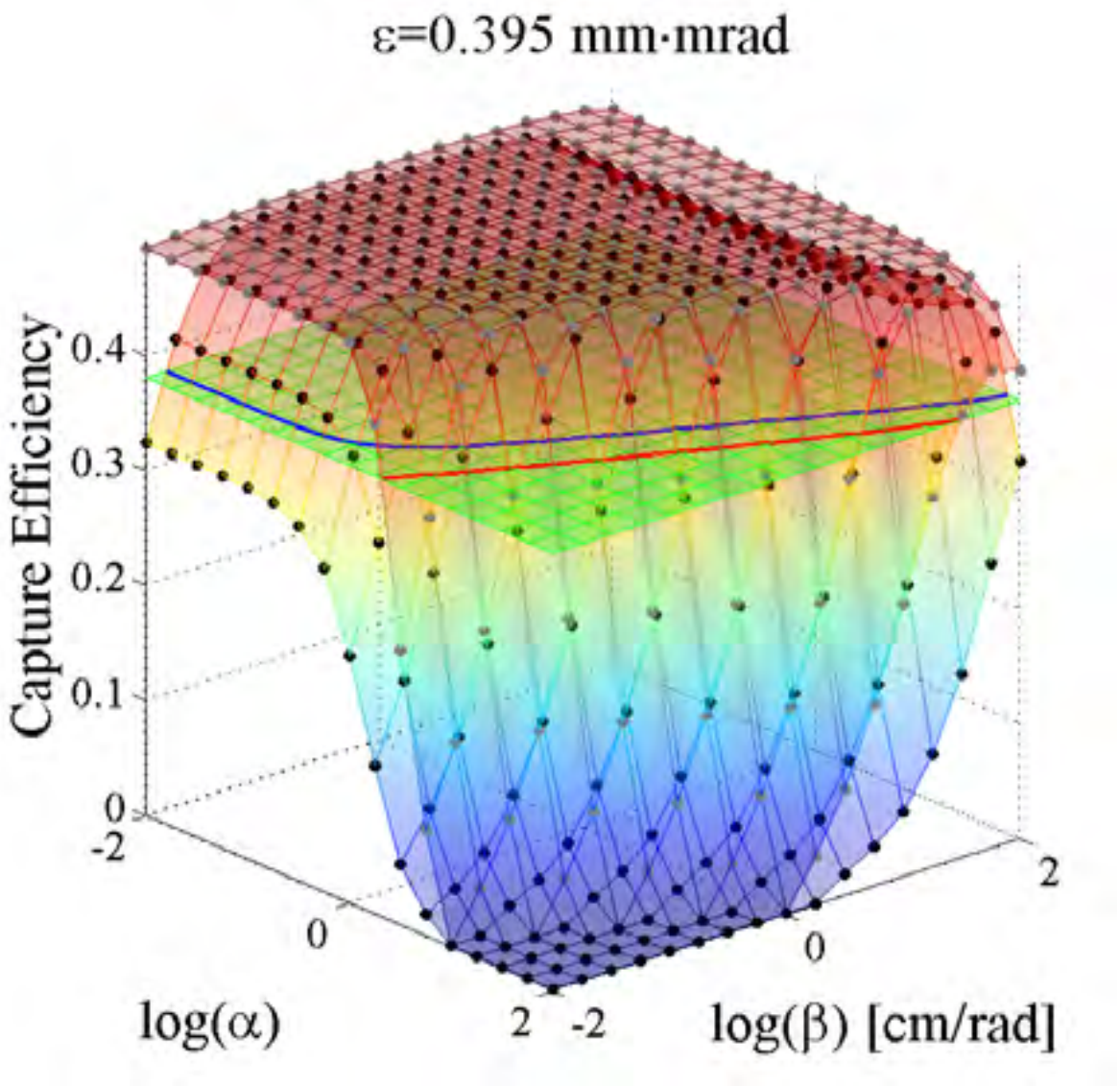
PARMELA - Phase space and beam profile (B=0)



PARMELA - Phase space and beam profile (B=0.15-0.25 T)

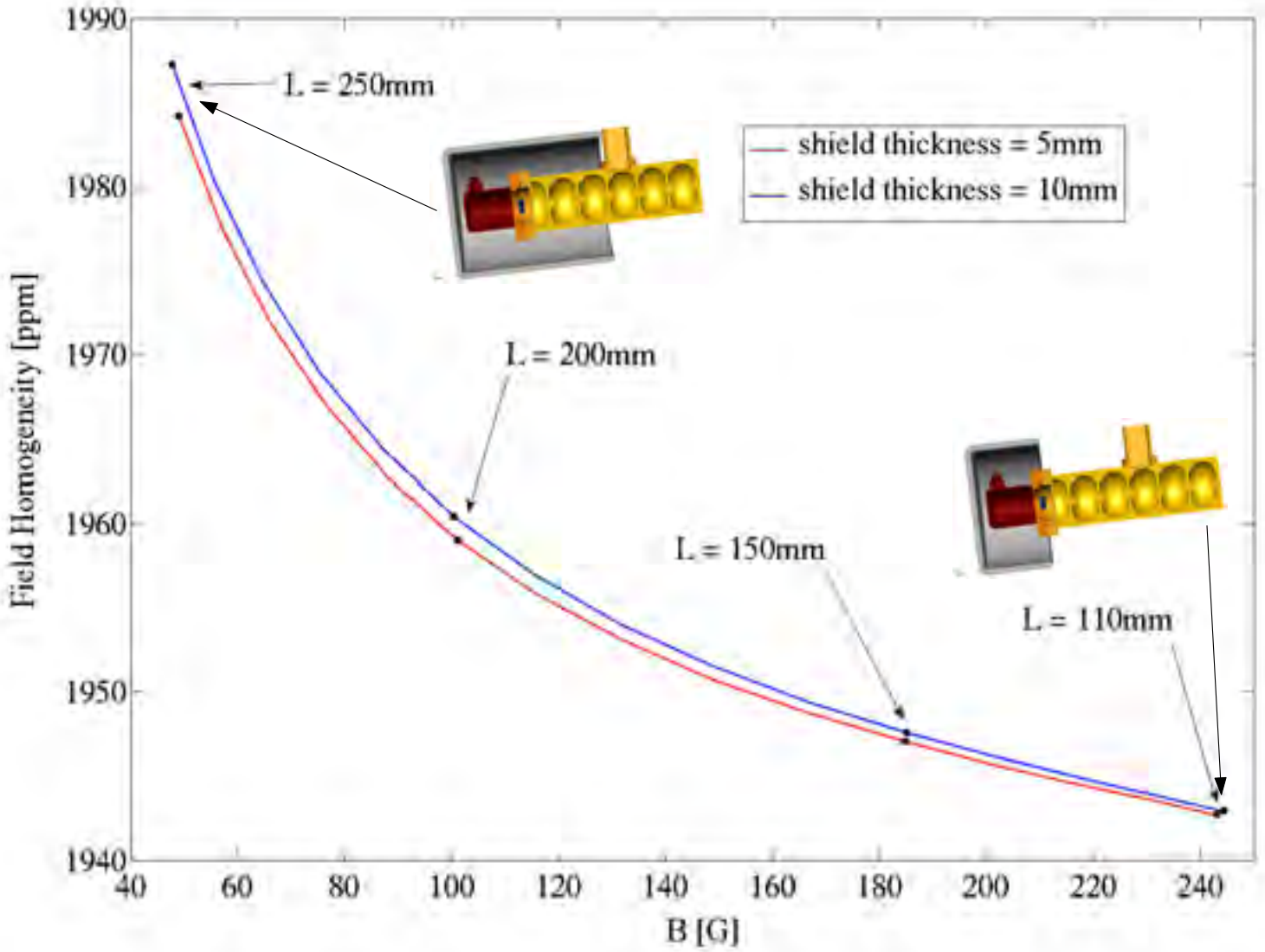


PARMELA - Capture Efficiency

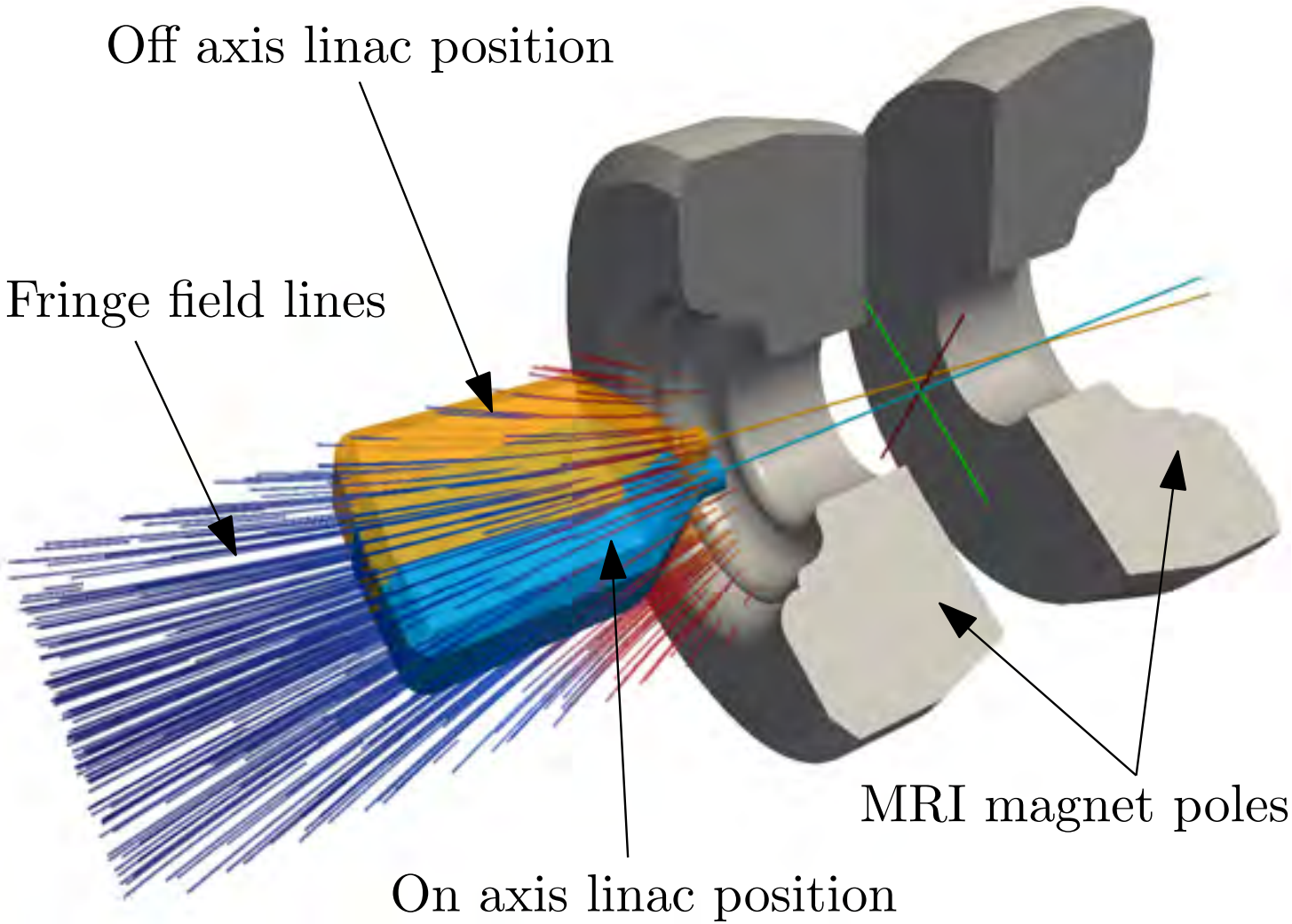


SOURCE: M. Constantin et al., *Phys. Med. Biol.*, **55**:N211-N214, 2010

Electron Gun Passive Magnetic Shielding

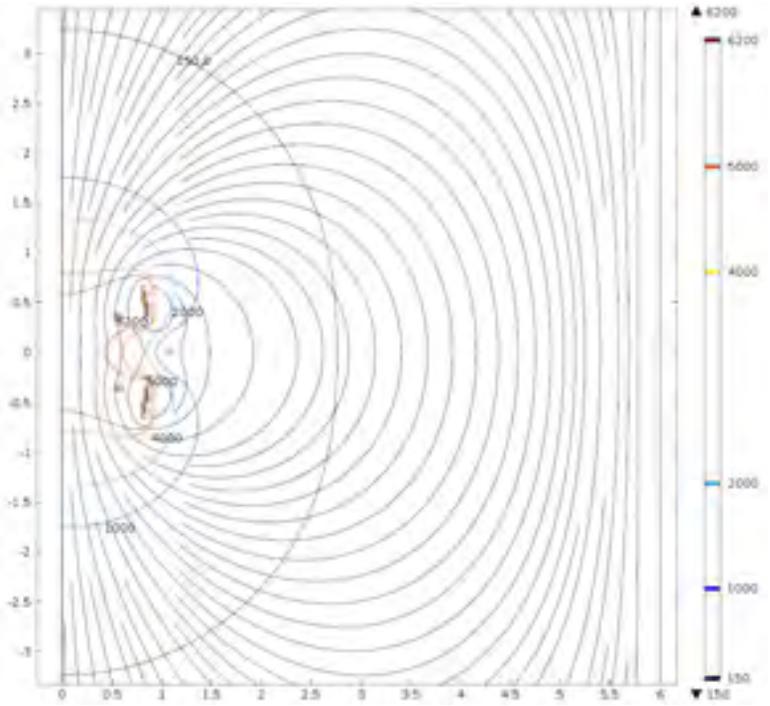


Robotic Linac Adaptation (RLA) Configuration



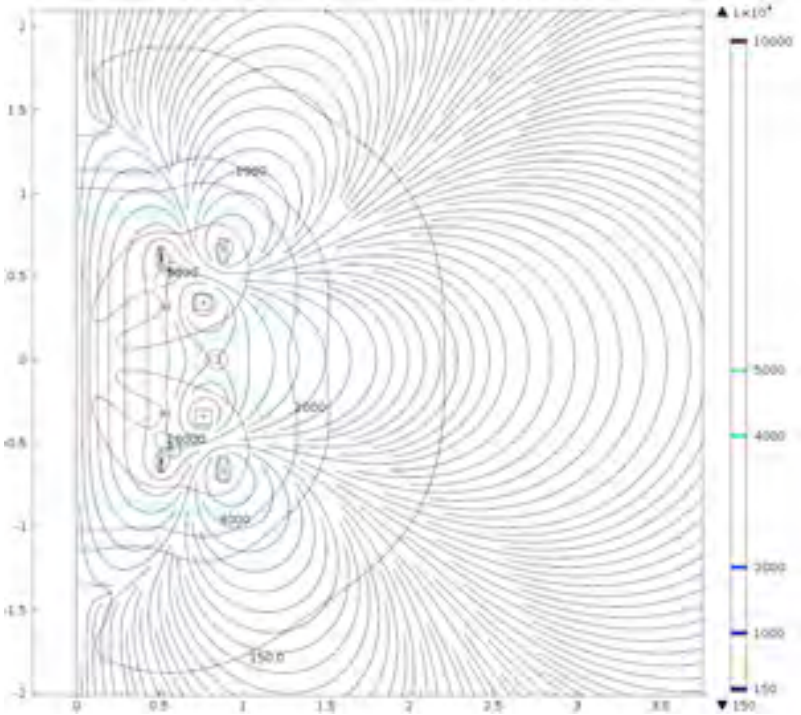
SOURCE: D. Constantin et al., *Med. Phys.*, **38**:3831, 2011

GE Signa SP (0.5T)



- Approximative solution

1T Actively Shielded Magnet



- No superconductors

- **BIG QUESTION: Can the active shield be designed such that the fringe field has a higher degree of homogeneity?**

Acknowledgments:

- Prof. Rebecca Fahrig (Stanford University)
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