In-line MRI-linac Configuration

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In-line MRI-linac Configuration

**Sources:**
Methods and Materials

0.5T GE Signa SP (mrT) - Side View

Electron Gun Model with Solution (0T)

References:

- **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

In-line MRI-linac Configuration

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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

**Current dependence on magnetic field**

**Anode Currents**

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
$\varepsilon_{rms} = 0.4\pi$ mm mrad, $\alpha_{rms} = 4.9$ (0T)
$\varepsilon_{rms} = 0.9\pi$ mm mrad, $\alpha_{rms} = 16.1$ (0.19T)

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

Optimized geometry for $B=0.19$T
- $d = 4$mm – 6mm, $\alpha = 80^\circ – 90^\circ$
- Emittance at 0.19T ($\alpha = 85^\circ$, $d = 5$mm)
Linac Capture Efficiency Dependence on Beam Injection Position

![Graph showing the capture efficiency of a linear accelerator as a function of beam injection position. The graph includes a marked experimental value at Z = 15 mm.]
COMSOL - Full Waveguide Solution

- Finite Elements: 594,772
- DOF: 11,488,251
- Memory: ~ 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

\[ \varepsilon = 0.395 \text{ mm}\cdot\text{mrad} \]
Electron Gun Passive Magnetic Shielding

![Graph showing field homogeneity versus magnetic field strength for different shield thicknesses and lengths.](image)
Robotic Linac Adaptation (RLA) Configuration

Fringe field lines

Off axis linac position

On axis linac position

MRI magnet poles

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