Electromagnetic Design of an Annular Coupled Accelerating Structure for the Advanced Compact Carbon Ion Linac

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Introduction

1. Radiotherapy with Carbon Ion

- Sharper Bragg peak – more precise radiotherapy treatment
- Greater radiobiological effectiveness (RBE) – able to treat more "radio-resistant' tumors

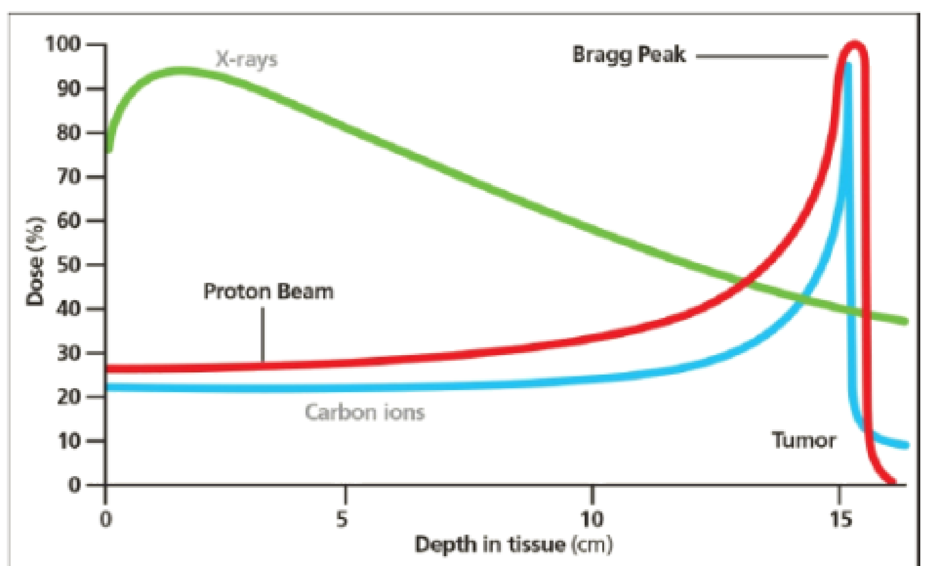

Figure 1: Comparison of Bragg peaks for x-rays, proton beams and carbon ion beams.

2. Advanced Compact Carbon Ion Linac (ACCIL)

- Linac – capable of delivering beams with variable energy (45 – 450 MeV/u) from pulse to pulse
- Compactness – high gradient structure

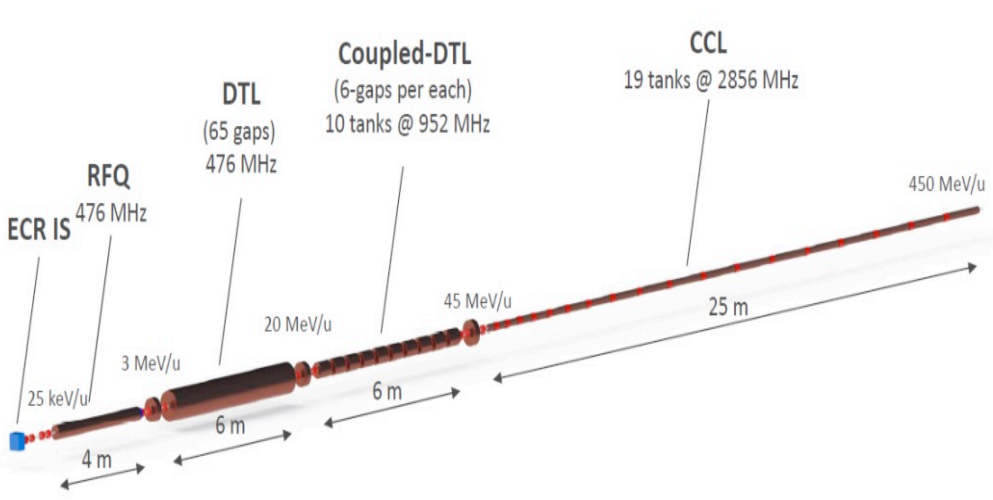

Figure 2: Schematic diagram of the different sections of ACCIL

3. Annular Coupled Structure (ACS)

- Standing wave π/2-mode structure

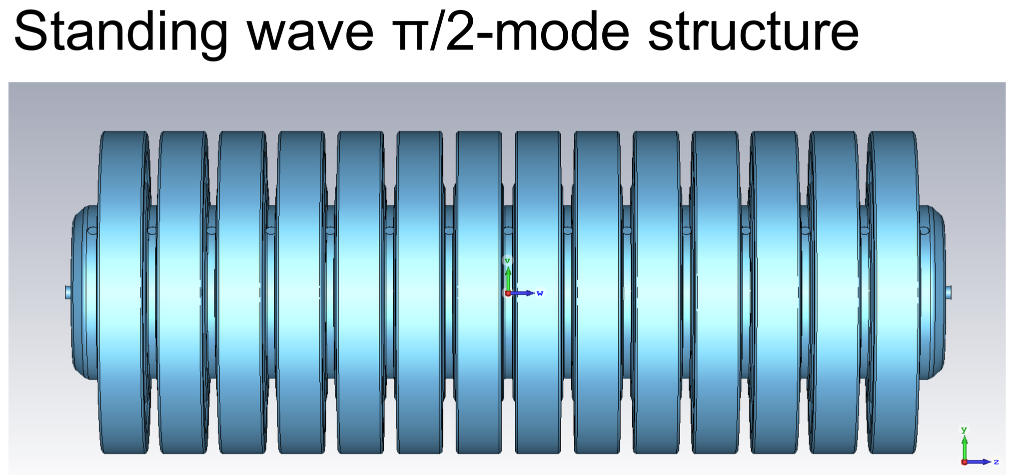

Figure 3: 3D model of an ACS cavity consisting of 15 accelerating cells and 14 coupling cells.

- Electromagnetic (EM) simulation with CST Microwave Studio to design and optimize the cavity for a resonant frequency of 2856 GHz and a flat field across all accelerating cells
- Sensitivity analysis to geometric errors
- Tuning capabilities

Optimization

1. Frequency

- Since the EM mode in each accelerating cell is TM010, the frequency is given by $f_0 = 2.405\times\frac{c}{2\pi R}$, we obtain the desired frequency of 2856 MHz by optimizing the cell radius of the accelerating cell.
- The optimum cell radius obtained is 38.853 mm.

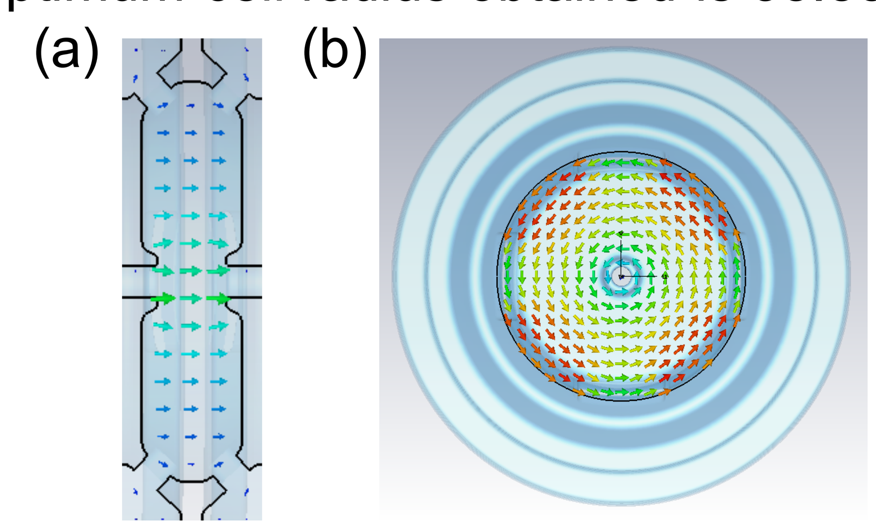

Figure 4: Electric [(a) left view] and magnetic [(b) front view] field in an accelerating cell, showing that the EM mode in each cell is TM010.

2. Field Flatness

- To simplify the manufacturing process, we only vary the geometry of the end cells of the cavity.
- Optimum parameters: cell gap = $0.4096\times$ drift tube length, and coupling window length = 28.17 mm.
- The variance of the peak E-field in each cell (E_{peak}) is

$$\sigma^2 = \sum\left(\frac{E_{peak} - \bar{E}_{peak}}{\bar{E}_{peak}}\right)^2 = 4.1060\times10^{-4}$$

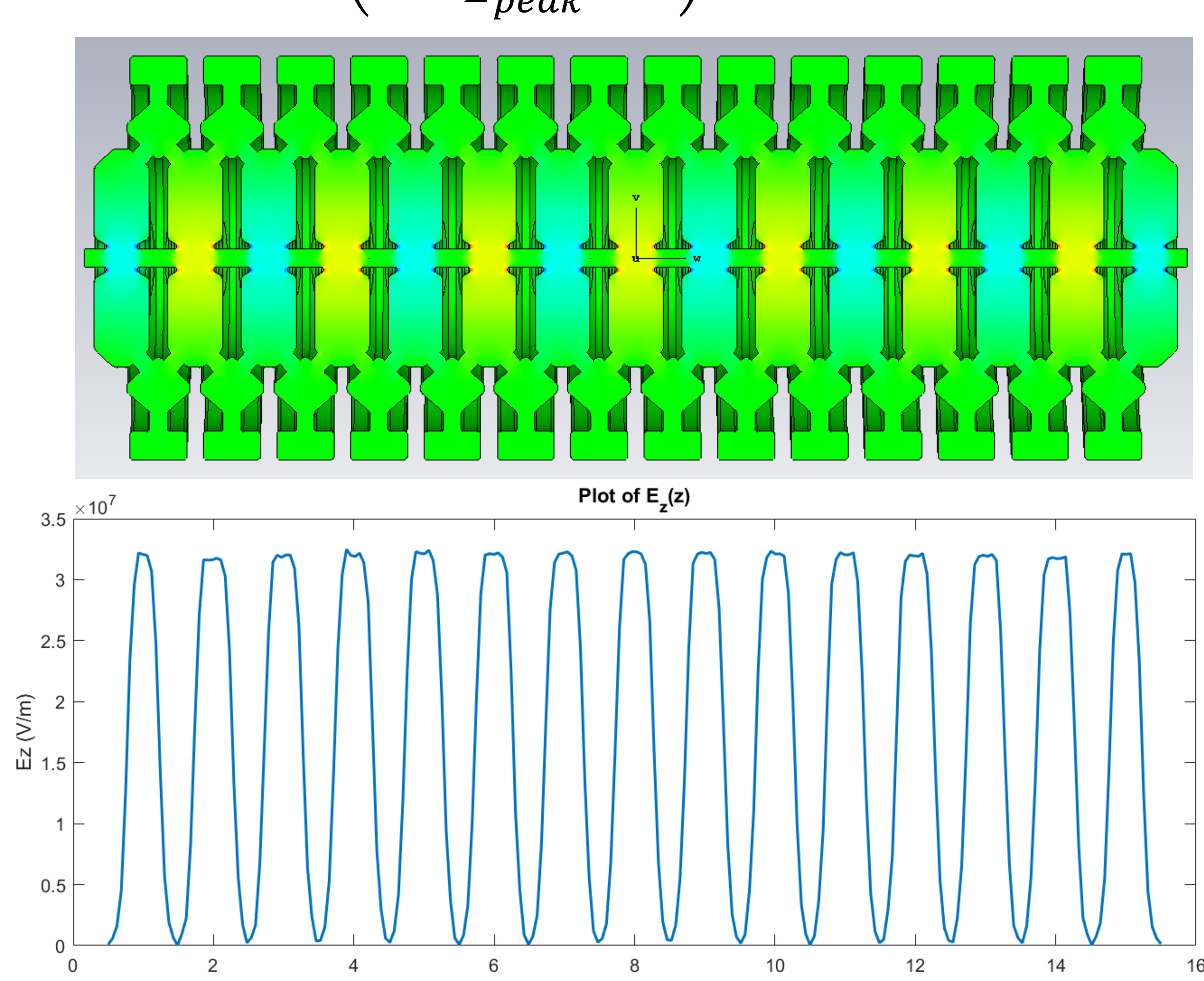

Figure 5: Plots of the electric field distribution in the optimized 15-cell structure.

3. Radio-Frequency (RF) Parameters

Frequency (MHz)	2.85600×10^3
Peak Electric Field (V/m)	7.92394×10^7
Peak Magnetic Field (A/m)	7.97734×10^4
Shunt Impedance (V/m)	1.79156×10^7
Q-Factor	9.04229×10^3

Sensitivity and Tuning

1. Sensitivity Analysis

- Assuming a machining precision of $\pm25\,\mu m$, we found the response function of the resonant frequency and the electric field distribution to small errors in the cell radii.

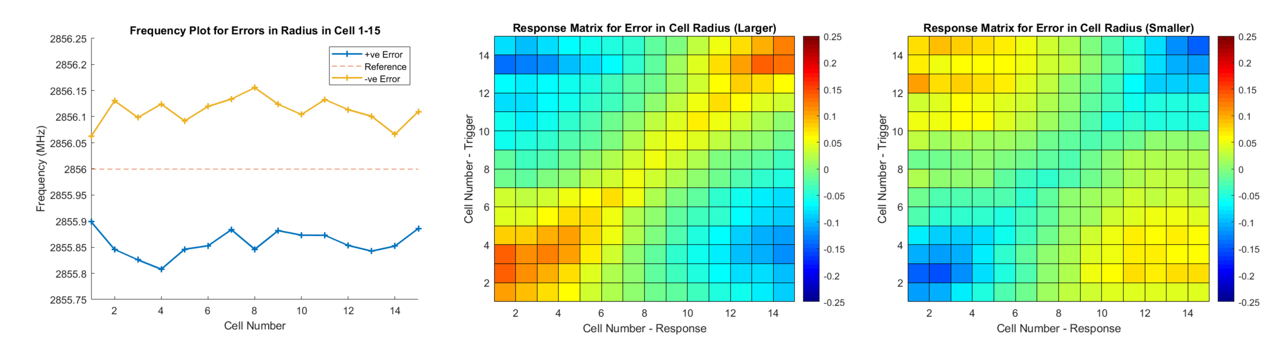

Figure 6: Change in resonant frequencies and E_{peak} in each cell when the radius of each cell is perturbed by $\pm25\,\mu m$.

2. Tuning

- Similarly, we studied the response functions of tuners installed on the accelerating cells.

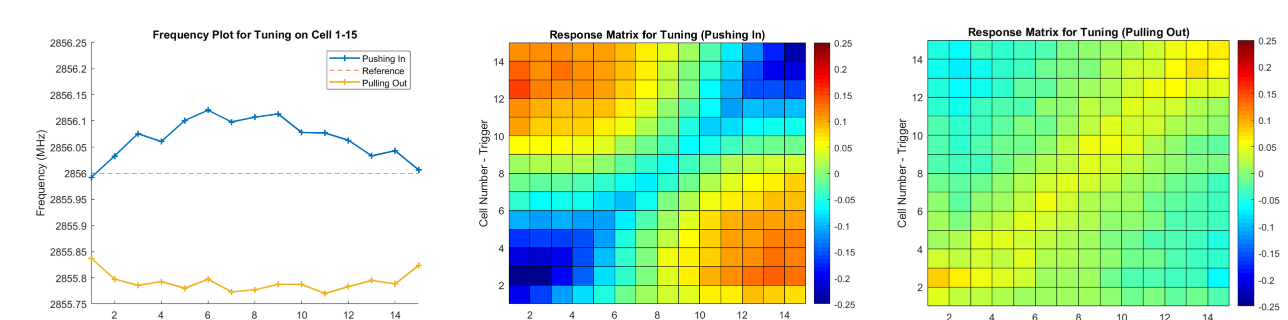

Figure 7: Change in resonant frequencies and E_{peak} in each cell when the tuners push into or pull out of the accelerating cell by 2 mm.

- These response functions can be used as a guide to tune the cavity back to the desired frequency and field flatness.

Conclusion and Future Work

- Field flatness can be achieved by only varying the cell gap and the coupling window length of the end cell, thus simplifying the manufacturing process.
- Resonant frequency is rather robust against errors in cell geometry; field flatness is relatively sensitive, but could be corrected by tuners.
- Future projects can look into engineering design and mechanical simulation, e.g., thermal properties, the exact cell deformation during tuning.

References

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[3] T. Wangler, *RF Linear Accelerators*, John Wiley & Sons, New York, 1998.

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