Study of Wakefields and Methods for Their Reduction in an Energy Recovery Linac

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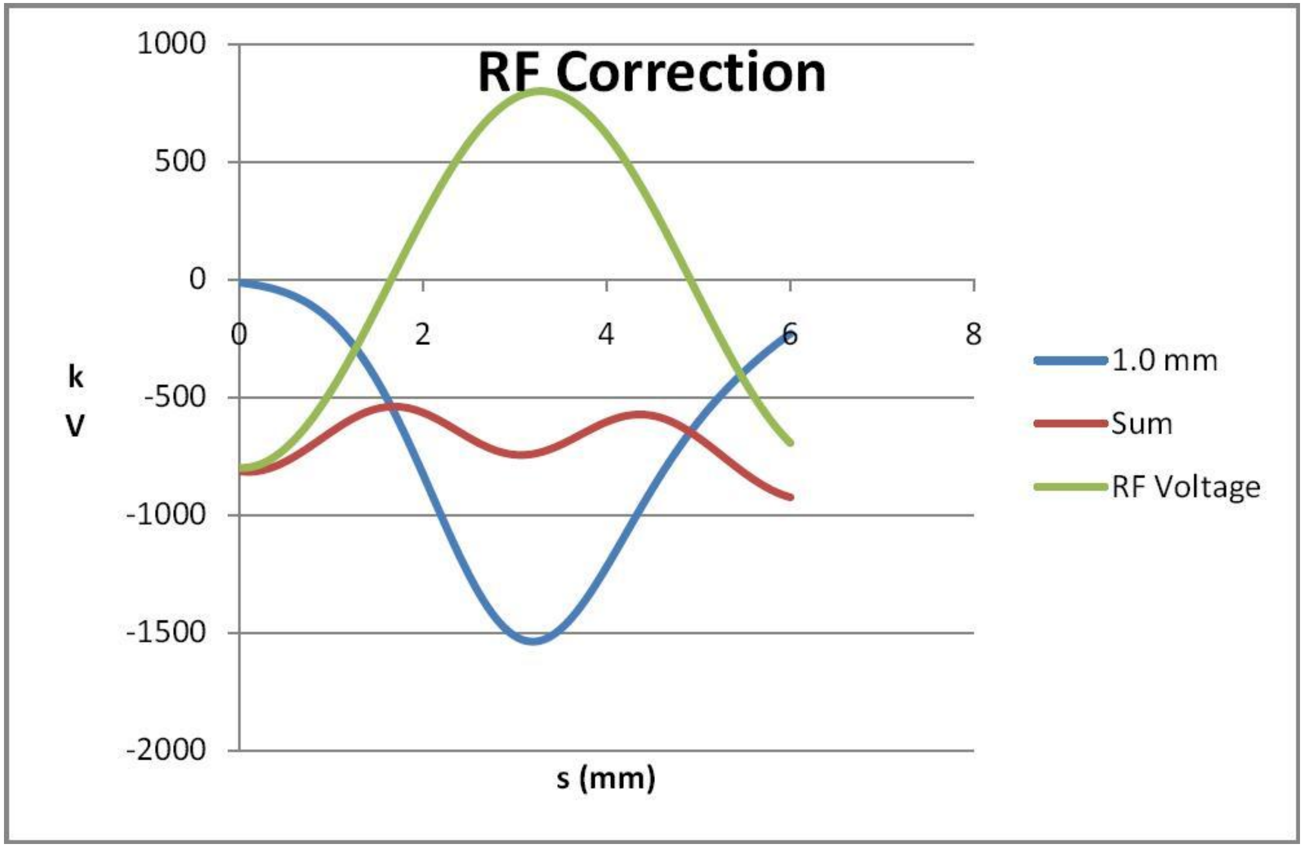
Project Overview

- The ERL is valued for its efficiency and capability to produce bright x-rays and short x-ray pulses.
- Wakefields can be obstructions that do not allow the ERL to achieve it's full potential:
  - Wakefields adversely affect energy spread.
- Energy recovery can be used via "dielectric power extractors" to mitigate wakefield effects.
- Design-oriented project focused on implementation of a "dielectric power extractor" in a two beam acceleration scheme.

RF Wakefield Correction

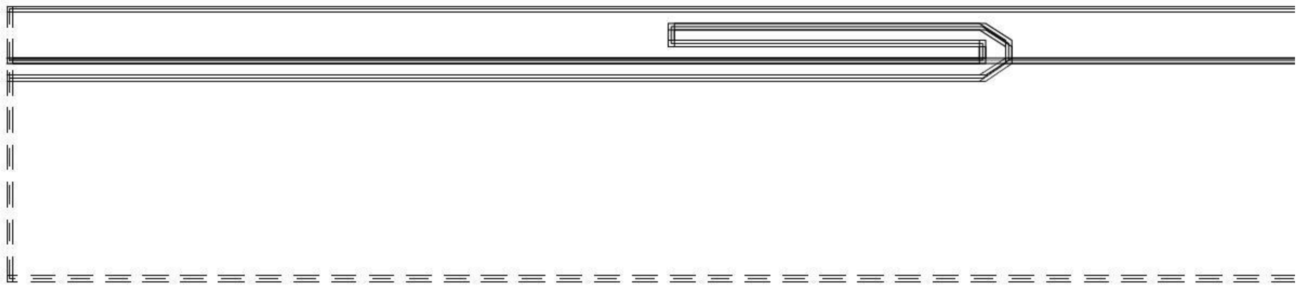
If it were possible to superimpose an RF voltage with an erroneous wakefield, one could improve bunch energy spread while accelerating the beam.

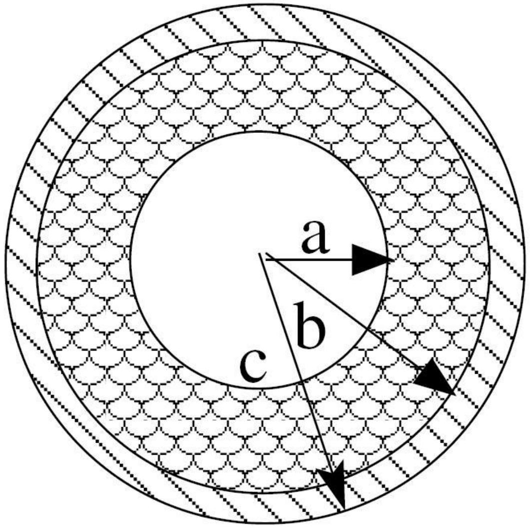


Goal - Frequency: 45 GHz, Amplitude: 1.6 MV

Dielectric Power Extractor

- Tested at Argonne National Laboratory.
- Cylindrically symmetric structure that has a thin lining of dielectric.
- Couplers attached to the endpoints of the dielectric layer



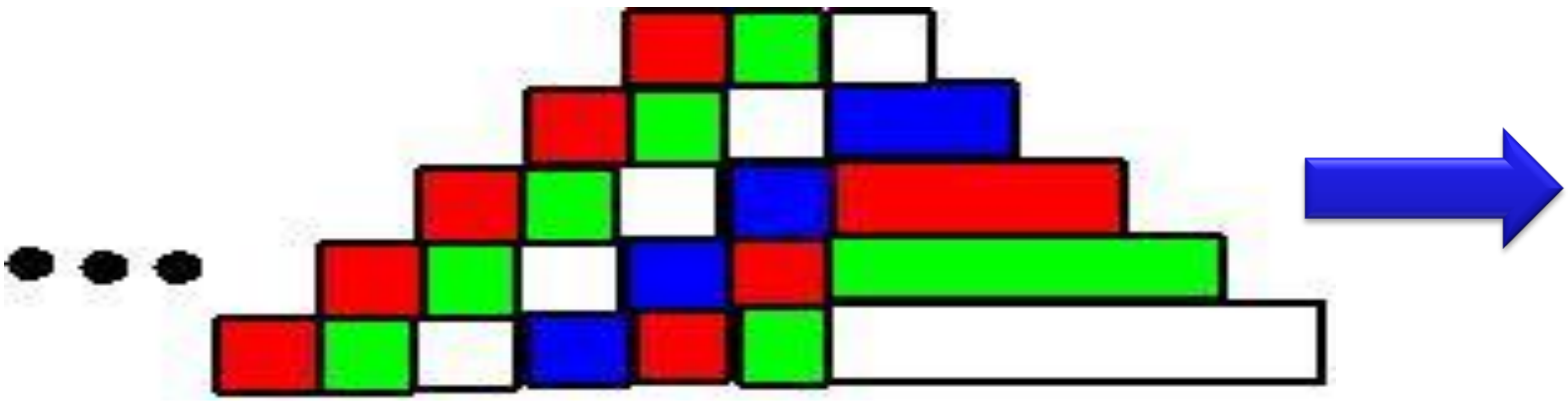


RF Power Extraction

1. The first bunch in a series of bunches traversing through the pipe at frequency ω enters the dielectric power extractor.
2. The bunch excites a wakefield at a specific mode based on the design of the structure.
3. The voltage is a function of the adjusted resonance frequency, the loaded quality factor (assume matched impedance condition), and the loss factor. The RF pulse propagates at a group velocity slower than the bunch velocity (assumed ideally relativistic).
4. The RF pulse is decays as the bunch leaves the dielectric power extractor. $V_{RF} = 2k(\omega'_{RF})q\cos(\omega'_{RF}t)e^{\left[-\frac{\omega'_{RF}t}{2Q_{loaded}}\right]}$
5. While the RF pulse is still propagating within the dielectric power extractor, a subsequent bunch enter the structure and excites its own RF pulse that superimposes with the tail of the existing RF pulse.

RF Power Extraction

- The wakefields extracted from neighboring bunches interfere constructively, producing a flat-top amplitude.



Tuning Requirements

- In order for the RF pulses to interfere constructively, the power extracting mode must be a harmonic of the bunch frequency.
- The desired frequency can be calculated as follows:

$$n = \left\lfloor \frac{Q_{loaded}\ \omega}{\omega_{RF}} \right\rfloor$$

$$\omega'_{RF} = \frac{2Q_{loaded}\ \omega}{n}$$

- Simulations suggest that by adjusting the coupler length, one can achieve a tuning range of ~200 MHz.

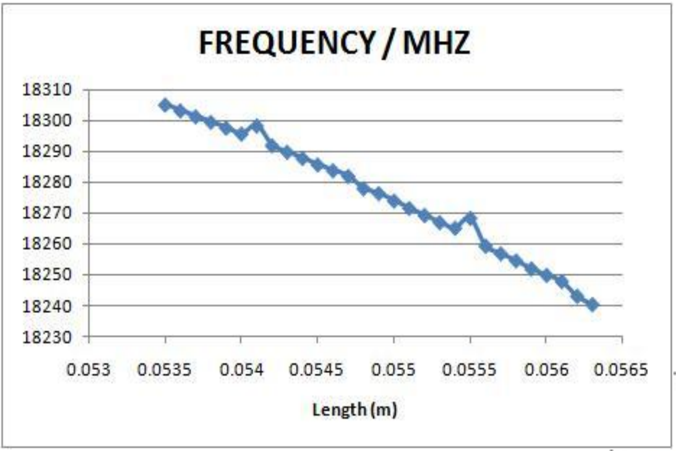
Simulations

- Attempted to optimize dielectric power extractor design by varying:
  - Dielectric layer length
  - Coupler length
  - Dielectric layer thickness
  - Taper length
- All parameters were varied independently and sequentially.
- Desirable features for a given mode were spatial localization, a high R/Q, and a high Q.

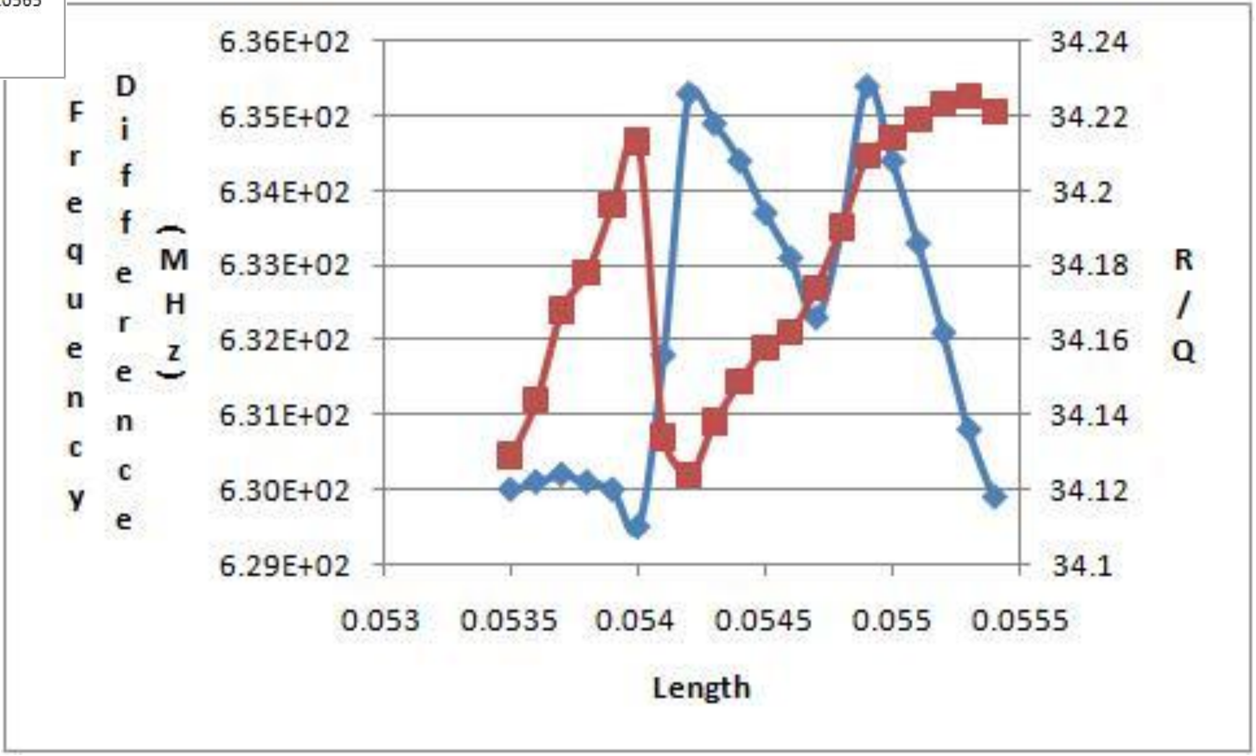
Trends Observed

- Frequency inversely related to length.
- When the R/Q for a given mode is maximized, the neighboring modes are more spread apart in frequency
- R/Q varies sinusoidally as the length of the couplers are varied
- The Q for a particular mode decreases as length increases

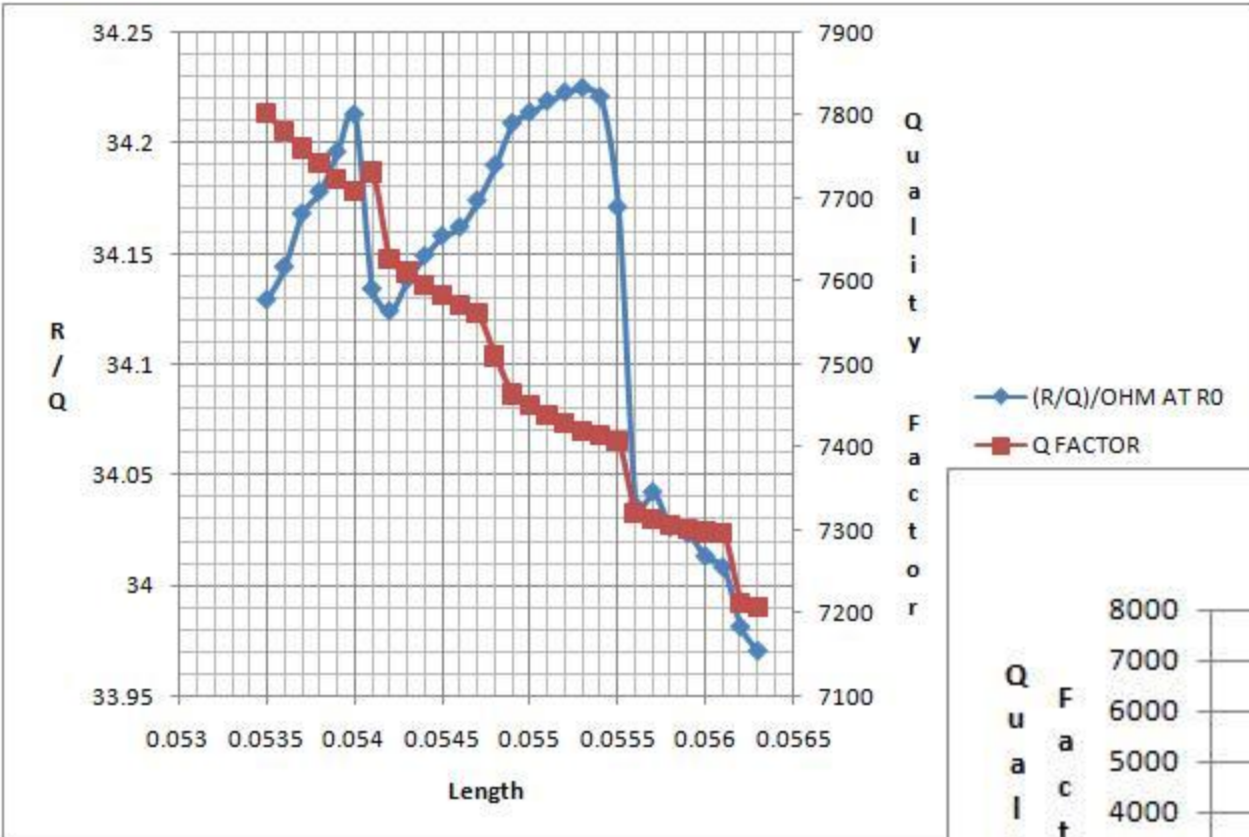
Length Variation

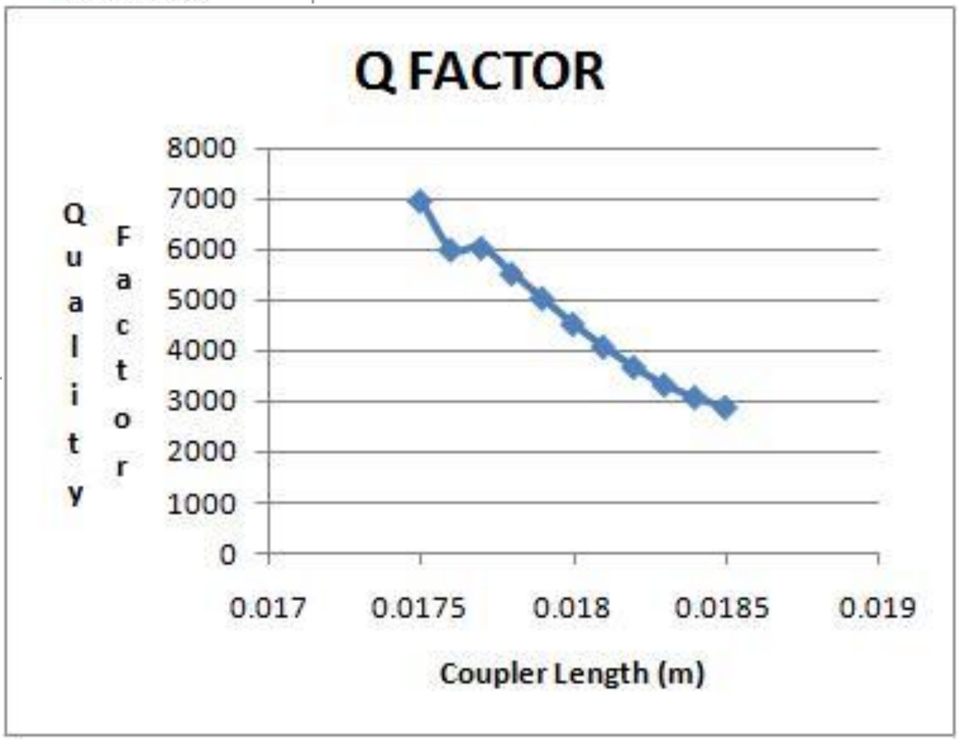


Trend discontinuities most probably explained by mesh allocation within dielectric

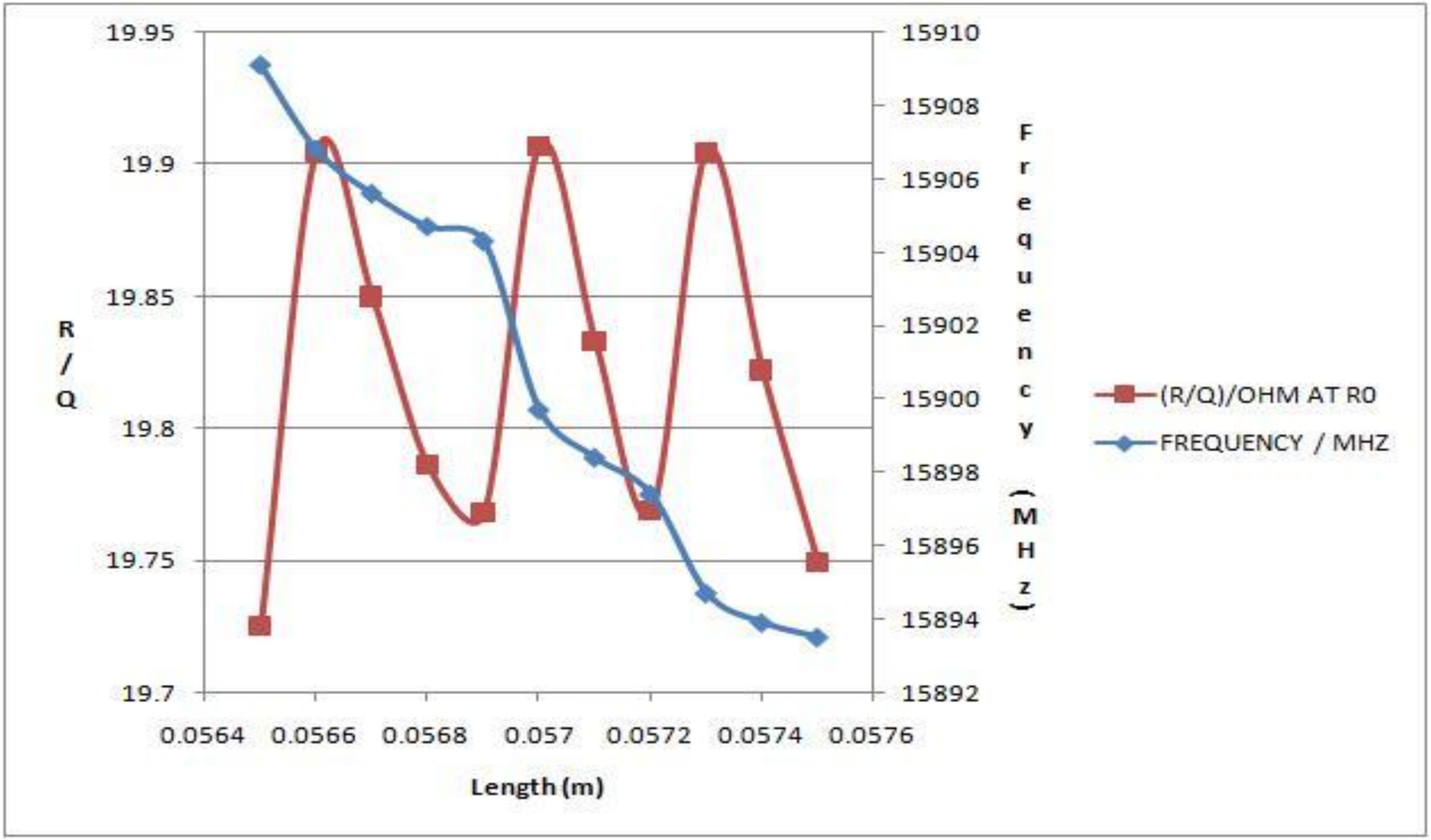


Q Factor Trend





R/Q Sinusoidal Behavior

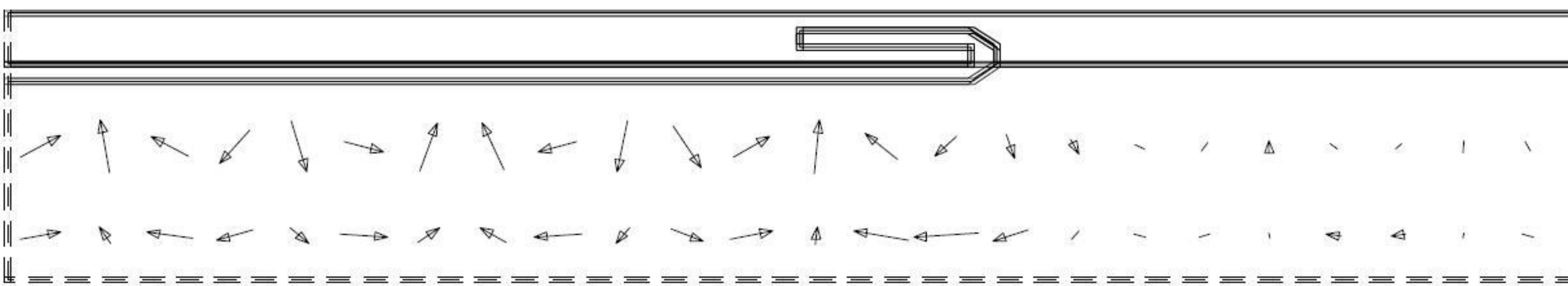


Demonstrates tuning plausibility (able to maintain R/Q while adjusting frequency within a ~200 MHz range)

Results

- Trapped modes found only when couplers were attached.
- Dielectric discontinuity was not enough (so far) to localize modes

Dielectric Length	Coupler Length	Frequency (GHz)	R/Q	Q-Factor
0.114 m	0.011 m	15.07	21.016	3848



Evaluation

- Calculations for the TBA scheme were done for the "optimal" mode.

Tuned Frequency	Peak RF Voltage
15.31 GHz	7.164 kV

- Required frequency within tuning range
- At least 2*140 dielectric power extractors are needed (i.e. ~2*21 = 42 meters of structure)
- Additional power extractors will be needed to account for attenuation in lossy walls.
- Bunch length will have to be adjusted

Conclusions

- The use of a dielectric power extractor to accelerate and decelerate the beam has much potential.
- Higher order modes with even more outstanding qualifications may exist but could not be searched for due to software limitations and time constraints.
- Notable discoveries:
  - Tuning the power extractor via minute length adjustments is feasible
  - Couplers play an important role in localizing modes

Acknowledgements

- Mike Billing
- Heather Williams
- Rich Galik
- Peter Wittich