Multi-Mode Cavity Optimization

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**Introduction**
- Standard accelerating cavities and injectors use a cavity operating at a single TM mode, typically TM 010. Here we explore the effects of multiple modes in the same cavity and how these modes can be mixed to achieve different goals. Our specific goal is to decrease the energy spread of a long bunch using TM 010 and TM 022 modes.

**Multi-Mode Cavities**
- The interactions between different TM modes change the field inside the cavity through superposition.
- Using a harmonic of the fundamental frequency of the cavity allows for easy implantation of higher frequency modes.
- TM0 10 is the standard accelerating mode (Blue).
- TM 022 is a third order harmonic (Orange).
- When combined they create a flatter wave which reduces energy spread (Green).
- Approximates a DC gun with AC fields.

**Cavity Design**
- Designed using Super Fish
- Modes chosen to decrease energy spread
- Beam Pipes included for fringe field effects (5 cm)
- Designed using Super Fish
- Bunch Length = 2.5 cm
- Energy Gain Limit (Within 0.001 Z (m)
- Frequency = 3.9 GHz
- Approximates a DC gun with AC
- TM 010 Mode
- Frequency = 1.3 GHz
- Cavity Length = 12 cm
- TM 022 Mode
- Frequency = 3.9 GHz
- Cavity Length = 12 cm

**Simulations**
- Simplex Optimizer Parameters
  - Energy Spread
  - Energy Gain
  - All Simulations were performed in General Particle Tracer (GPT)
  - Transverse Magnetic Modes
  - TM 010
    - Frequency = 1.3 GHz
    - TM 022
    - Frequency = 3.9 GHz
  - Bunch Length = 2.5 cm
  - Macro Particles = 1,000,000
  - Starting Energy = 2 MeV
  - No Space Charge Effects

**Results**
- TM 010 Mode
  - Energy Spread = 9.02e-03
  - Final Bunch Energy = 3.999 MeV
- TM 010 and TM 022 Mode
  - Energy Spread = 2.8e-04
  - Final Bunch Energy = 4.001 MeV

**Discussion**
- Different combinations of TM modes can induce different effects on the beam.
- Sharpening the accelerating field to increase energy gain in the cell.
- Cell focusing effects.

**Conclusion**
- The TM 010 and TM 022 mode combination showed the best energy spread reduction.
- Further research into different mode combinations for maximizing field gradient are being performed.
- Possible building and testing of tabletop system in the future.

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