External quality factor: What is going on inside a half-wave resonator?

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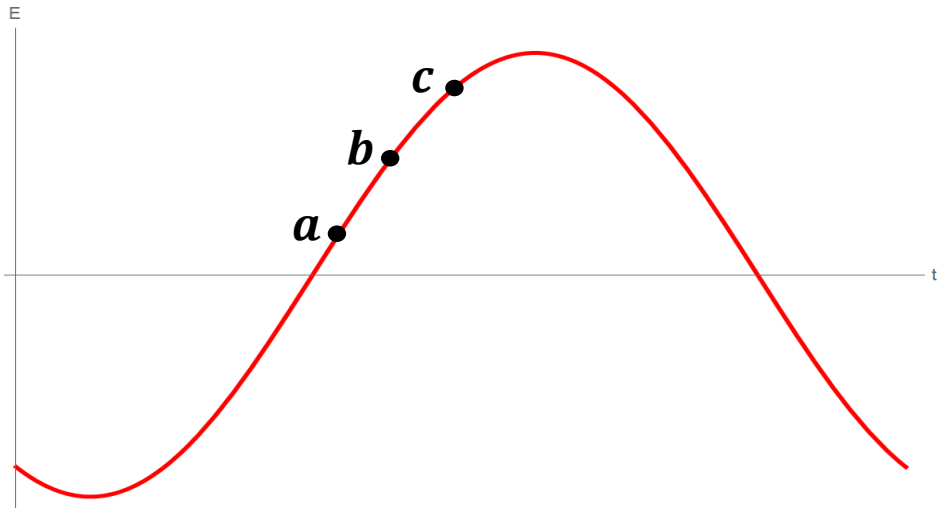
Why?

- Accelerating cavities use resonant electromagnetic (EM) fields to accelerate and focus particle bunches
  - we use half-wave resonators
- Need to monitor EM field
  - Amplitude: amount of acceleration of the bunch
  - Phase: amount of acceleration and longitudinal focusing of the bunch

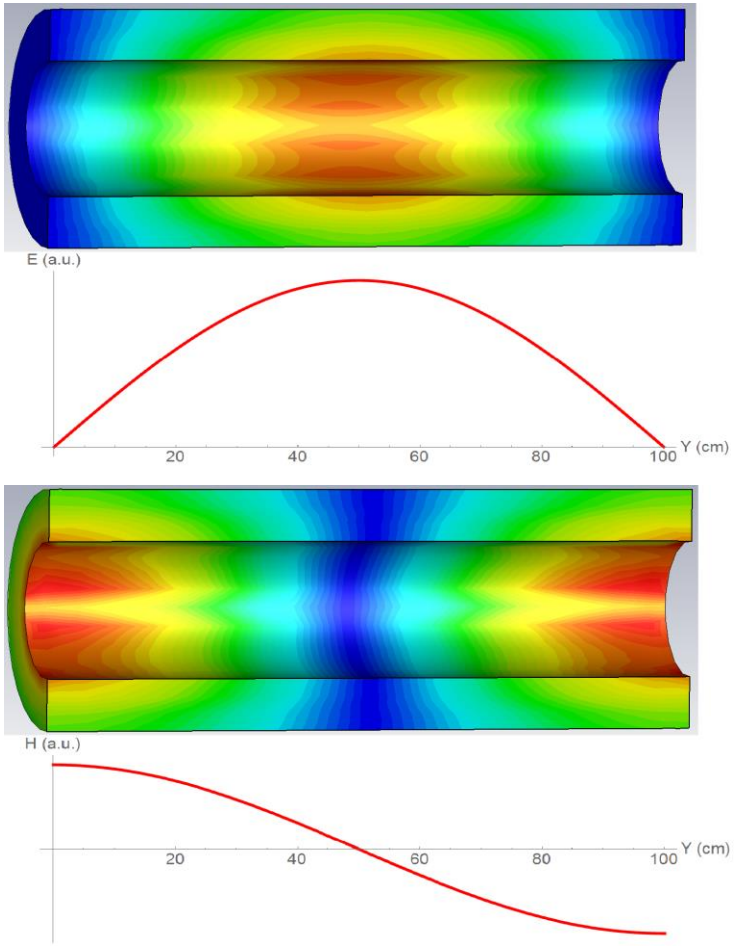


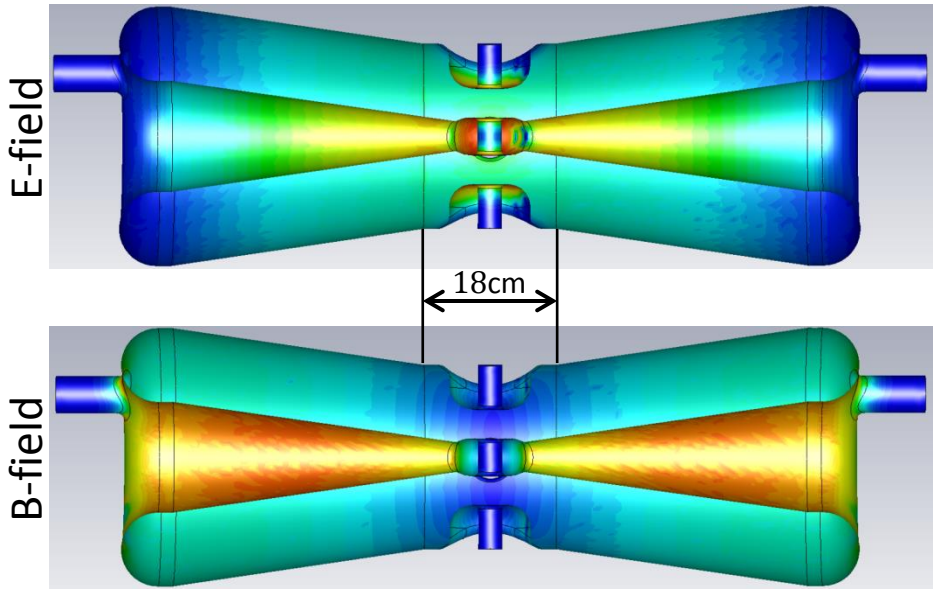
<u>Focusing with phase</u>

- Particle $\boldsymbol{a}$ arrives first
  - most initial energy
  - receives smaller acceleration
- Particle $\boldsymbol{b}$ represents ideal particle
  - enters cavity at synchronous phase
- Particle $\boldsymbol{c}$ arrives last
  - least initial energy
  - receives greatest acceleration

What is a half-wave resonator (HWR)?

- A HWR resonates transverse electric and magnetic (TEM) modes
  - must be a coaxial line
  - fundamental mode is a half-wavelength
  - beam axis is where E-field is maximum for maximum acceleration
- Our HWR is used to accelerate H^- ions
  - $f_0 = 162.5$ MHz; $\beta = 0.112$
  - superconducting niobium





Above: The volume electric (top) and magnetic (bottom) fields shown as a contour plot for an ideal coaxial line. The plots under each figure show the general half-wave shape of the respective field amplitudes.
Left: The volume electric (top) and magnetic (bottom) fields shown as a contour plot for our HWR.

*for contour plots, blue corresponds to low magnitudes, red corresponds to high magnitudes.

External quality factor for half-wave resonators

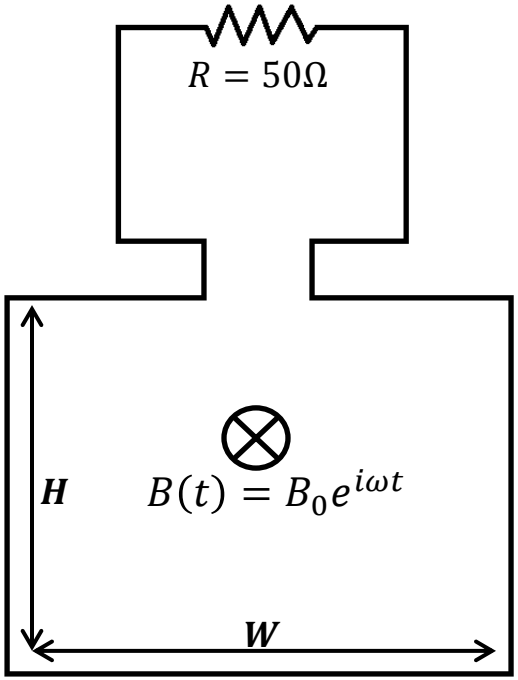
- We need to couple power out of the cavity.
  - from Faraday's law: use changing magnetic field

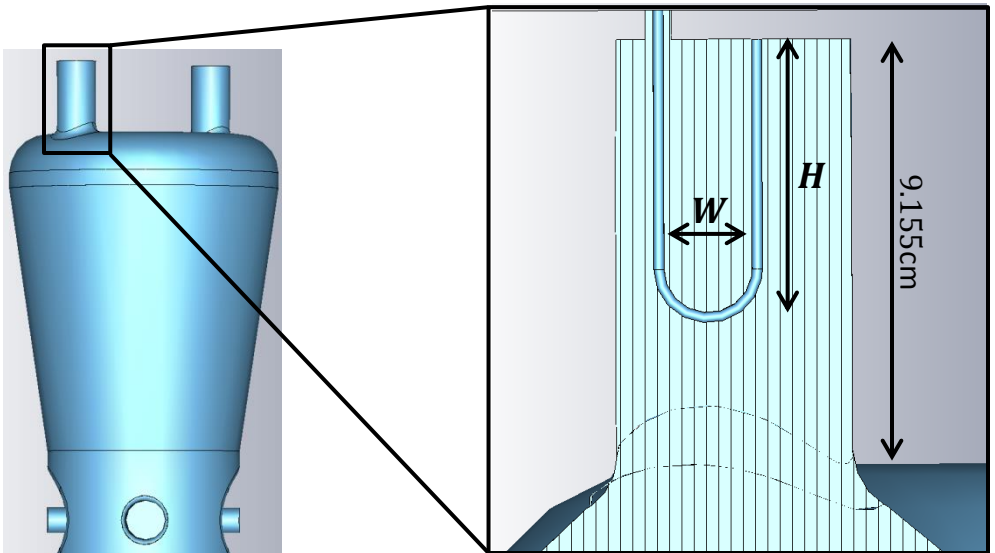
$$\mathcal{E} = -\frac{d\Phi}{dt} = -\frac{d}{dt}\iint \boldsymbol{B}\cdot d\boldsymbol{a}$$

  - calculate power from induced voltage
- A convenient parameter is the external quality factor:

$$Q_{ext} = \frac{\omega_{rf}\, U}{P_{out}}$$

  - External quality Q_{ext}: losses out of couplers
  - Loaded quality Q_L: total losses





Above: The circuit drawn is an ideal square loop used for hand calculations.

Left: We put a coupling loop in one of the ports on the top of the cavity. The zoomed-in figure is a cross-section view of the port showing the loop geometry.