

#### TE Wave Simulations

Danielle Duggins

Introduction Electron Clour Motivation TE Wave Method Grooved Chamber Simulation

Simulations

Frequency Scans Determination of Resonances Shortening Grooved Length Electron Cloud

Experimenta Bead Pull Method

End Matter

# Modeling of Resonant TE Waves for Electron Cloud Density Measurements in CesrTA

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Research Experience for Undergraduates, 2012



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# Introduction



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# Electron Cloud in Particle Accelerators

- At CesrTA, primary Low Energy Electrons are produced from synchrotron radiation (photoelectrons), which may lead to production of secondary electrons.
- Electron clouds cause instabilities in the positron beams which limit the maximum beam current in the accelerator.





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# Measuring Electron Cloud Density

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Methods for Measurement of Electron Cloud Density in CesrTA

- Measuring Beam Response to E-Cloud (e.g. Tune Shift)
- Collection of electrons and current measurement (RFA & Shielded Pickup)
- TE Wave Method



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# Measuring Electron Cloud Density

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Methods for Measurement of Electron Cloud Density in CesrTA

- Measuring Beam Response to E-Cloud (e.g. Tune Shift)
- Collection of electrons and current measurement (RFA & Shielded Pickup)
- TE Wave Method

Reasons for Using TE Waves:

- Non-Invasive
- Cheap
- Localized over Finite Length/Volume
- Cross-Check with Simulation and other Measurement Techniques



# TE Wave Technique

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### How it Works

Uses existing Beam Position Monitor buttons to couple microwaves into the beam-pipe

### What it does

Measures resonant frequency shift – proportional to e-cloud density in the volume





# Grooved Chamber

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### Purpose

### Attenuation of Electron Cloud Density





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### Purpose

### Attenuation of Electron Cloud Density



# Installation of new beam-pipe assembly in L3

Grooved Chamber



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### Purpose

### Attenuation of Electron Cloud Density



### Installation of new beam-pipe assembly in L3

Grooved Chamber



Experimentally: it was observed that it was possible to trap waves within grooved pipe section at the right frequencies

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# VORPAL

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Vorpal solves Maxwell's equations numerically & handles both particles and fields.



# VORPAL

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Vorpal solves Maxwell's equations numerically & handles both particles and fields.

### Bérenger's PML

unphysical; serves purpose of absorption of wave; as if it were an infinitely long pipe



Smooth-Grooved-Smooth Pipe with PMLs at each end in Vorpal



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# Simulation Data



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# Frequency Scans

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### **Cutoff Frequencies**

Cutoff frequencies were found using simulation for smooth and grooved geometries. As expected, grooved geometry had lower cutoff. Smooth:  $f_c = 1.974$  Grooved:  $f_c = 1.875$  GHz



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# Frequency Scans

### Cutoff Frequencies

Cutoff frequencies were found using simulation for smooth and grooved geometries. As expected, grooved geometry had lower cutoff. Smooth:  $f_c = 1.974$  Grooved:  $f_c = 1.875$  GHz



MATLAB was then used to plot voltage data from VORPAL along length of beam-pipe.

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# Determination of Resonances

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### Phase Difference

Resonances will have an average phase shift close to zero or  $\pi$  rad, indicating that the part of the wave is in or exactly out of phase.

- Standing waves were determined using amplitude, shape, and phase of E-field along the pipe
- Phase shift calculated relative to drive point at x = -6.67cm
- Average Shift in Grooved Section only  $= 0.022035\pi$  rad.





TE Wave

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# Determination of Resonances



#### Simulations

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Position Along Length (cm)

Phase Difference Plot:

- Close to zero indicates in-phase portions of wave
- Close to π rad indicates exactly out-of-phase portions



# TE Wave **Frequency Scans** Simulations Determination of Resonances

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# Frequency Shift from Shortened Grooved-Pipe

### $\underline{n=1 \text{ Mode}}$

Shortening length of grooved section shifts frequency up, as expected from behavior of standing waves







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E-Field, 66cm Grooves, (=1.9145 GHz

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# Frequency Shift from Shortened Grooved-Pipe







Resonant Frequencies: 66cm: f = 1.9145 GHz 33cm: f = 1.9167 GHz16.5cm: f = 1.9177 GHz



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# Resonant Frequency Shift Due to Electron Cloud

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### Resonant Frequency Shift

 $= \frac{e^2}{2\epsilon_0 m_e \omega^2} \frac{\int_V n_e E_0^2 dV}{\int_V E_0^2 dV}$  $\Delta \omega_n$ ω



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# Resonant Frequency Shift Due to Electron Cloud

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Frequencies of 1 <sup>34</sup> Resonance (GHz)			
Grooves	E-Cloud Density		
	No e <sup>-</sup>	1 <i>e</i> 14	2e14
Whole	1.9045	1.907	1.910
Half	1.9068	1.910	1.912
Quarter	1.9107	1.913	1.916

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this agrees well with the equation

### Resonant Frequency Shift

$$\frac{\Delta\omega_n}{\omega} = \frac{e^2}{2\epsilon_0 m_e \omega^2} \frac{\int_V n_e E_0^2 dV}{\int_V E_0^2 dV}$$



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# Resonant Frequency Shift Due to Electron Cloud

### Resonant Frequency Shift

$$\frac{\Delta\omega_n}{\omega} = \frac{e^2}{2\epsilon_0 m_e \omega^2} \frac{\int_V n_e E_0^2 dV}{\int_V E_0^2 dV}$$

Frequencies of 1<sup>st</sup> Resonance (GHz) E-Cloud Density Grooves No  $e^{-}$ 1e14 2e14 Whole 1 9045 1 907 1.910 Half 1 9068 1 910 1.912 Quarter 1 9107 1 913 1.916

this agrees well with the equation

Frequencies of 2 <sup>nd</sup> Resonance (GHz)					
Grooves	E-Cloud Density				
	No e <sup>-</sup>	1e14	2e14		
Whole	1.9146	1.9155	1.917		
Half	1.9167	1.9175	1.918		
Quarter	1.9177	1.9185	1.919		

this doesn't agree quite as well :(



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# Experimental Results



# Bead Pull Method

**Resonant Cavity** 



Bead Pull Method



$$\frac{\Delta\omega}{\omega} = \frac{\int_{V} (1-\varepsilon_{r}) E_{0}^{2} dV}{2 \int_{V} E_{0}^{2} dV}$$

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# Bead Pull Method



### Bead Pull on L3 Beam-Pipe



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New beam-pipe assembly for installation in L3 was measured using bead pull method.



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# Bead Pull Method

### Spectrum Analyzer



- Microwaves were coupled into BPM buttons
- Bead Pull Method was performed for several resonances at each BPM detector
- "Trapped Modes" were observed in grooved sections of the beam-pipe assembly
- 6 or 8 measurements were taken at each BPM detector  $\circ_{\circ \circ \circ}$



# Bead Pull Results I

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### n = 1 and n = 2 Modes Inside Aluminum Grooved Section





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# Bead Pull Results II

### n = 3 Mode Inside Aluminum Grooved Section



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### Bead Pull Results III







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### Conclusions

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#### Simulations

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• Bead Pull Method showed trapped modes in grooved chamber, which agrees with the standing waves produced in simulation data



# Conclusions

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- Bead Pull Method showed trapped modes in grooved chamber, which agrees with the standing waves produced in simulation data
- Both simulation and experiment show *n* = 3 mode to propagate out into smooth chambers



# Conclusions

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- Bead Pull Method showed trapped modes in grooved chamber, which agrees with the standing waves produced in simulation data
- Both simulation and experiment show *n* = 3 mode to propagate out into smooth chambers
- Simulation data with electron cloud for n = 1 mode agreed well with theory while n = 2 mode did not agree well



# Conclusions

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- Bead Pull Method showed trapped modes in grooved chamber, which agrees with the standing waves produced in simulation data
- Both simulation and experiment show *n* = 3 mode to propagate out into smooth chambers
- Simulation data with electron cloud for n = 1 mode agreed well with theory while n = 2 mode did not agree well
- It seems that measurements of electron cloud density within the newly installed grooved chambers should work well using the TE Wave Method



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### Thank you!

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### Thank you! Questions?

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