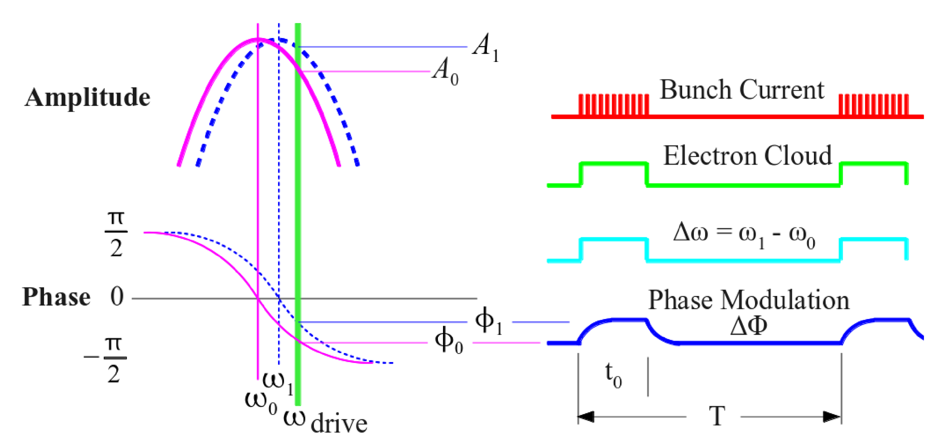
Electron Cloud Density Measurements Using Resonant Microwaves at CESRTA*

J.P. Sikora†, CLASSE, Ithaca, New York, USA
S. De Santis, LBNL, Berkeley, California, USA

Periodic EC Density Generates Sidebands

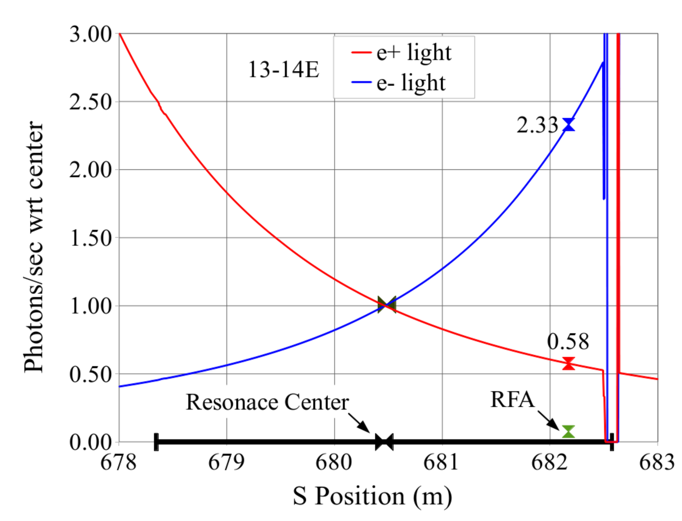
Resonant frequency shift due to EC density: The resonant frequency shift produced by an electron cloud (EC) density $\boldsymbol{n_e}$ in the absence of an external magnetic field is given by the equation below. The integral is over the resonant volume V of the beam-pipe and E is the electric field of the microwaves. With a drive frequency on or close to resonance, a periodic EC density will generate phase modulation sidebands in the received signal.

$$\frac{\Delta\omega}{\omega_0} \approx \frac{e^2}{2\varepsilon_0 m_e \omega_0^2} \frac{\int_V n_e E^2 dV}{\int_V E^2 dV} \qquad (1)$$

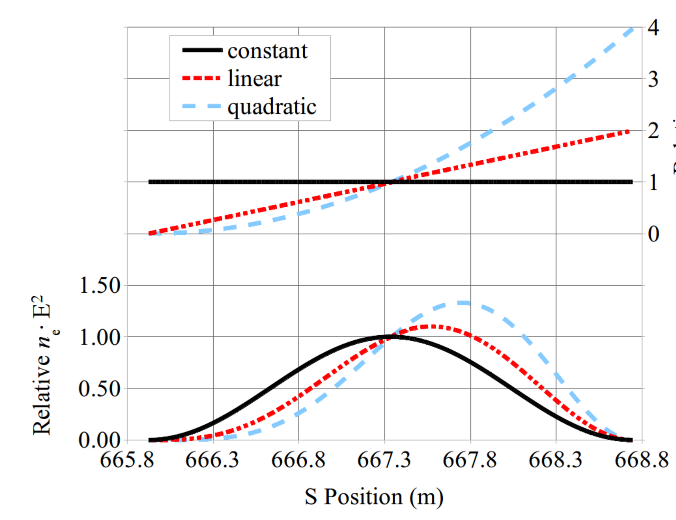


Abstract
Hardware has recently been installed in the Cornell Electron Storage Ring (CESR) to extend the capability of resonant microwave measurement of electron cloud density. Two new detector locations include aluminum beam-pipe in a dipole magnet and copper beam-pipe in a field free region. Measurements with both positron and electron beams are presented with both beams showing saturation of the electron cloud density in the aluminum chamber. These measurements were made at CESR which has been reconfigured as a test accelerator (CESRTA) with positron or electron beam energies ranging from 2 GeV to 5 GeV.

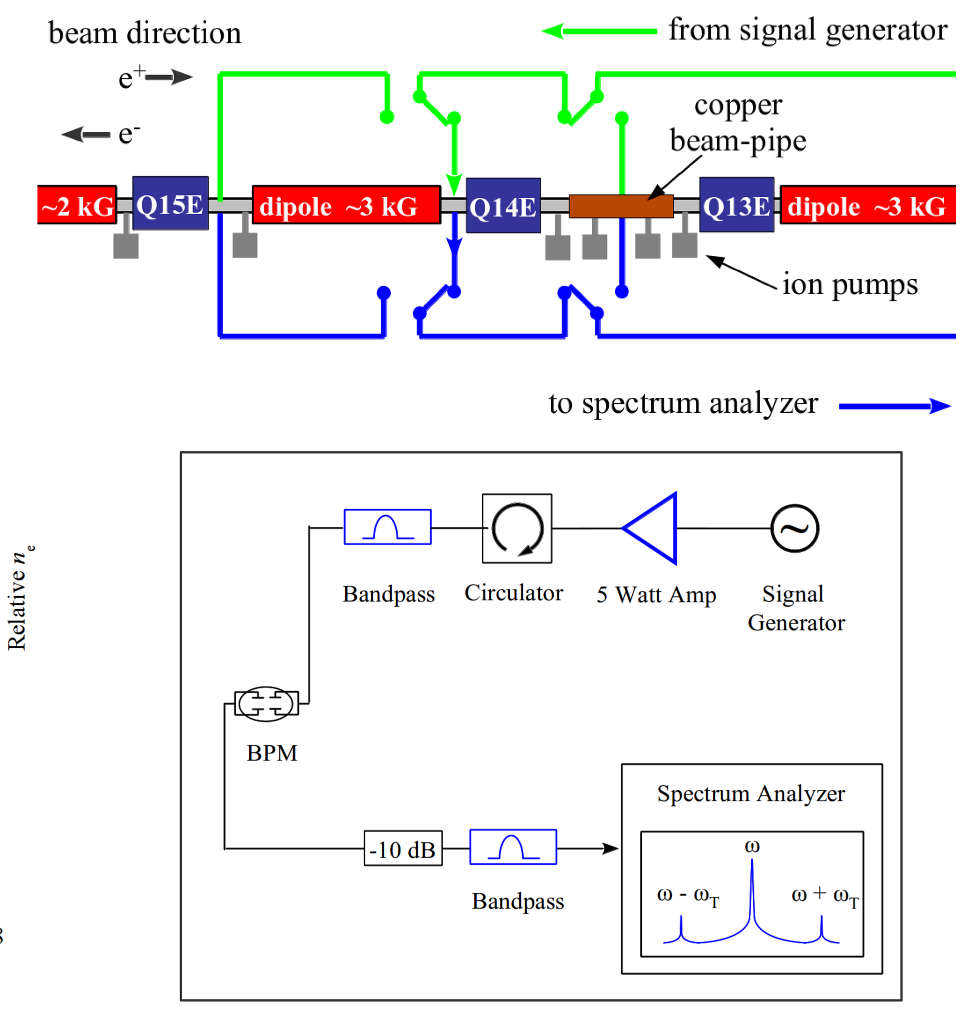
EC Density Changes with Position



The EC density at CESR is generated primarily by synchrotron radiation. The plot above shows that synchrotron radiation changes by a factor of 5 over the resonance length at 13-14E.

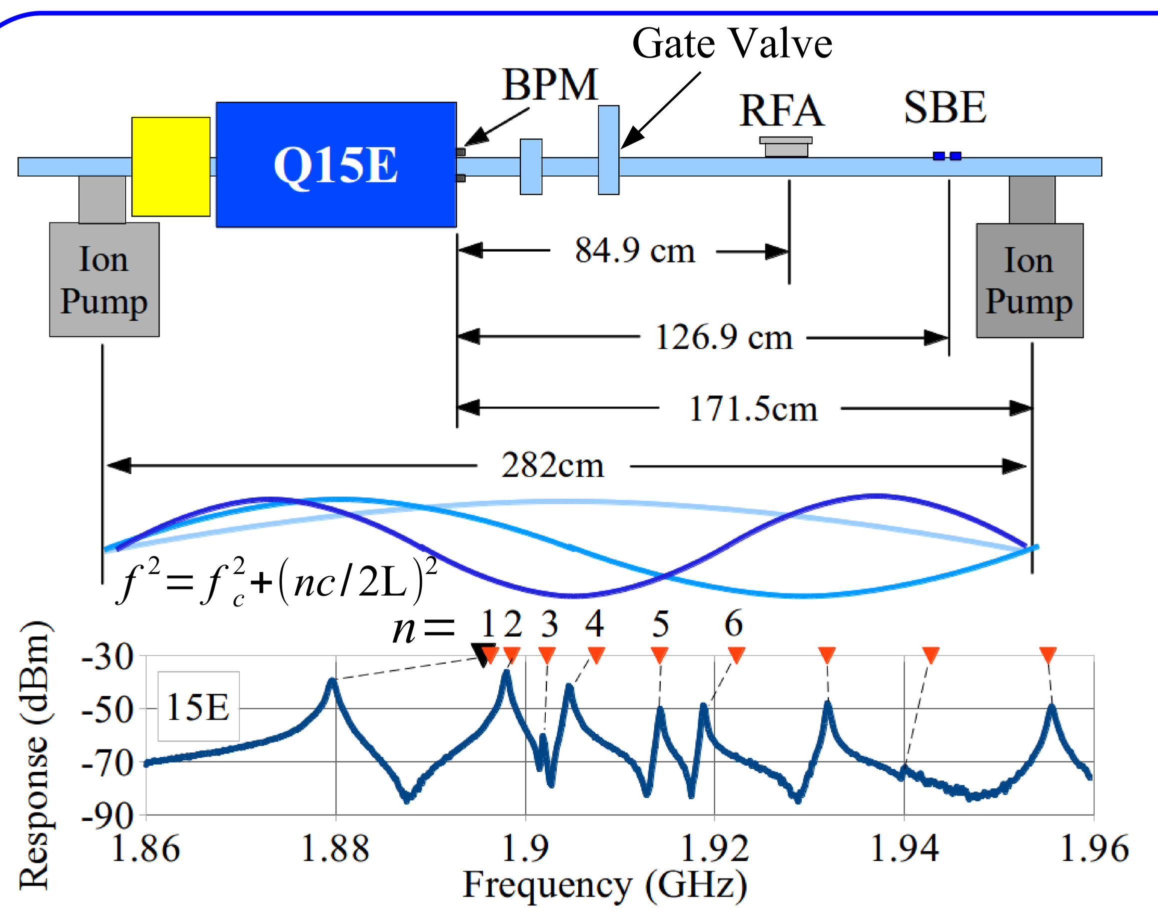


A non-linear change in EC density with position will affect the integral of Eq. 1. We make the approximation that the EC density is proportional to the synchrotron light in order to calculate a compensation for this effect so that the density at the resonance center can be calculated.



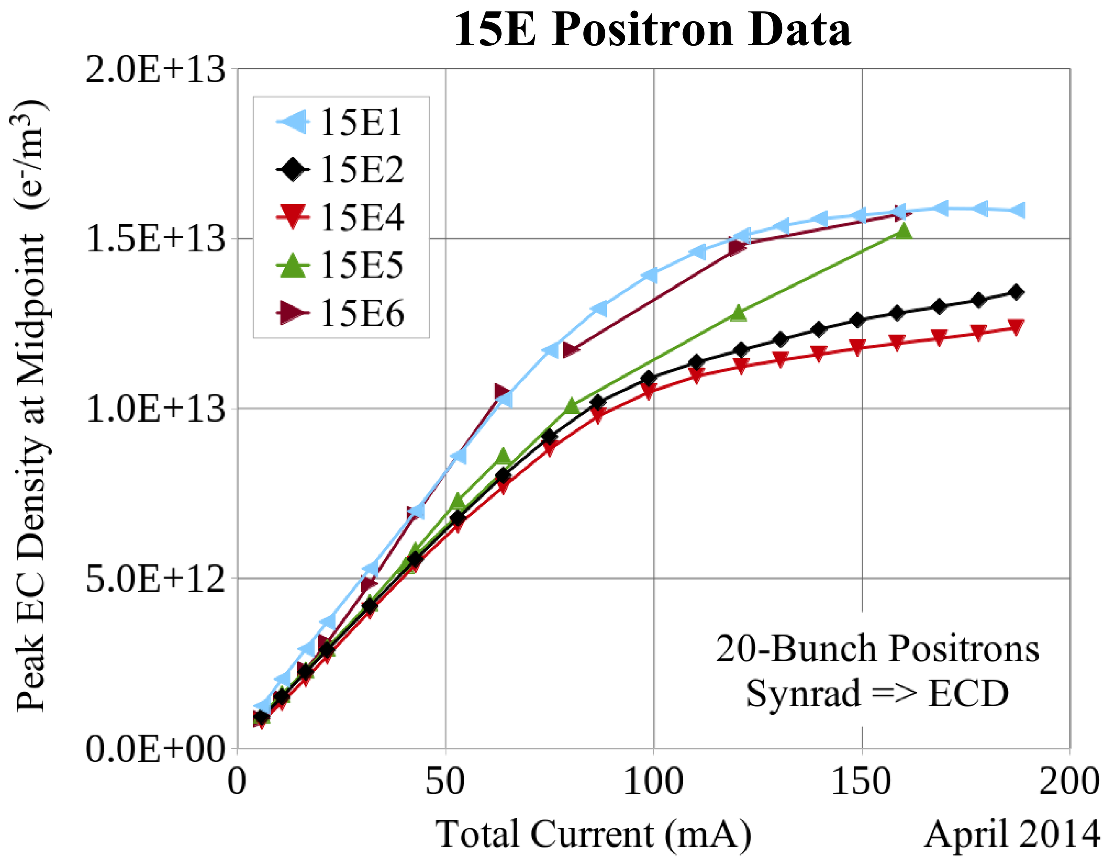
Hardware: The drive and receive signals are routed to/from three locations in the 13-15E sector of CESR (upper). The instruments needed to make an EC density measurement are shown in the lower part of the figure.

All beam data shown below was taken by injecting a 20-bunch train at 5.3 GeV and acquiring data from all three detectors at each current step. The bunch spacing is 14 ns with a revolution period of 2562 ns. A single 1 mA bunch has a population of 1.6×10^{10} particles.

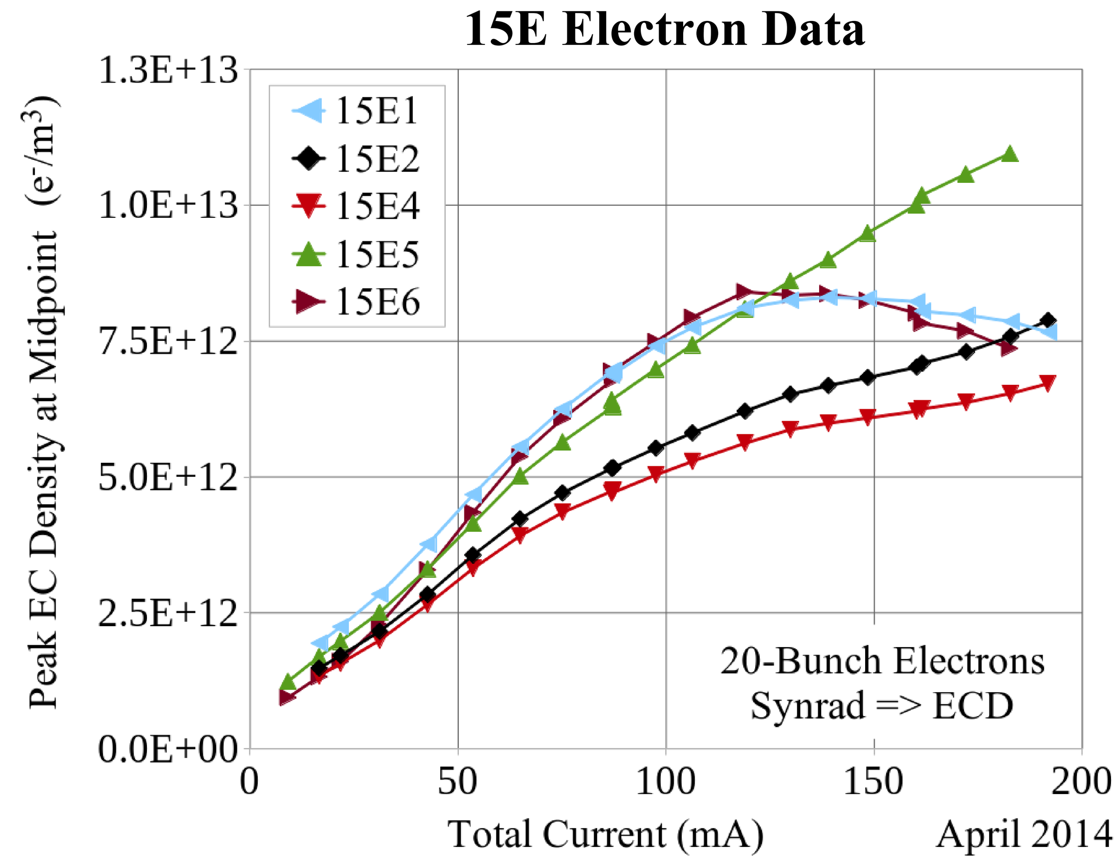


Reflections at ion pumps produce resonances in the beam-pipe, with the response measured at 15E shown above. The peaks do not follow a resonant series very well. It is suspected that the larger volume in the gate valve pulls the some of the resonant frequencies lower.

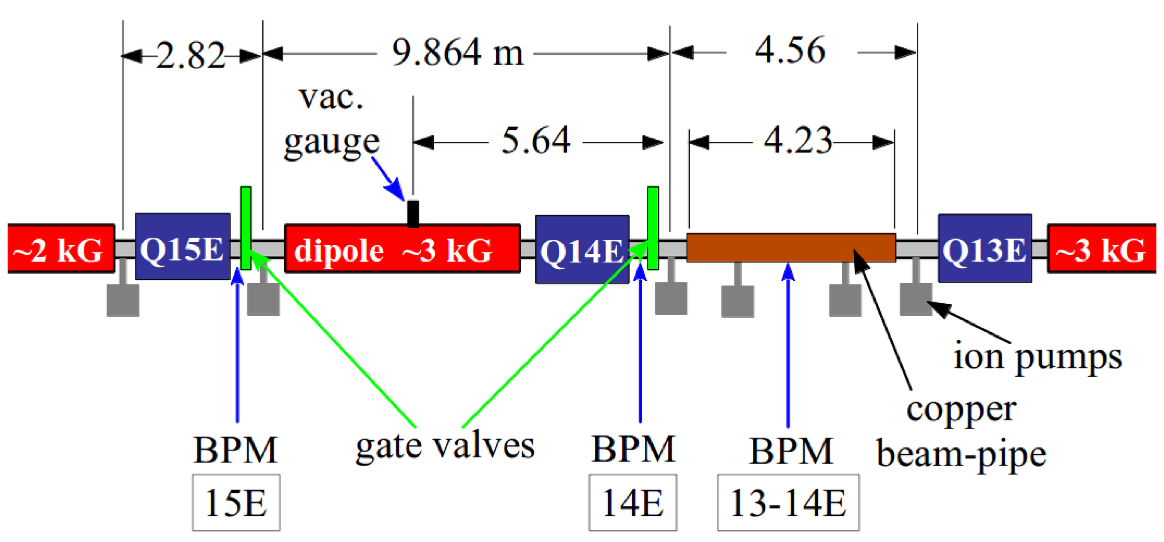
15E Positron Data



15E Electron Data

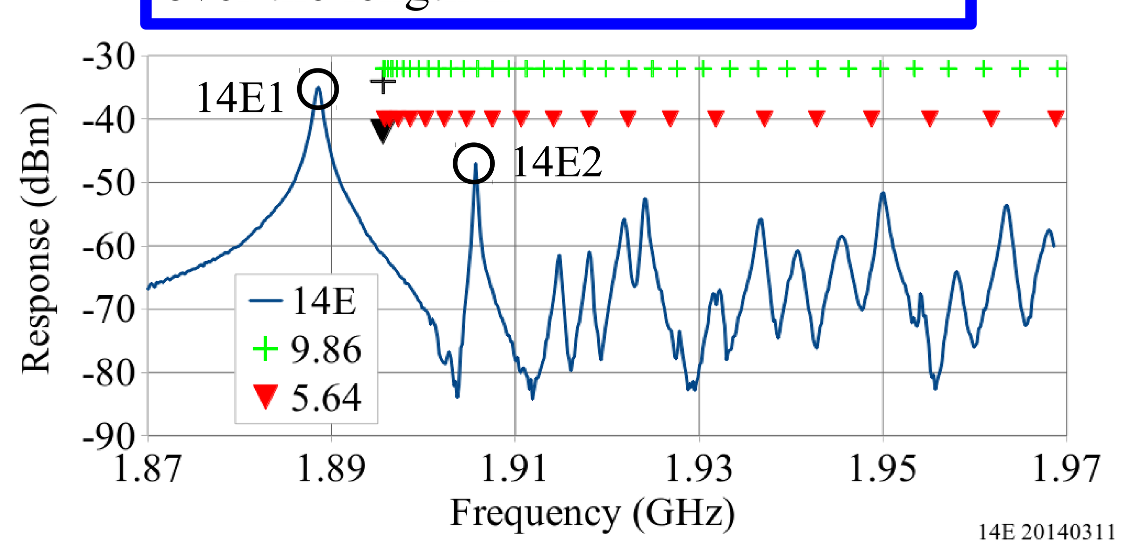


The 15E aluminum chamber shows saturation at the highest bunch currents with positrons. This is also true for electrons, but the data from different resonances have different behavior.



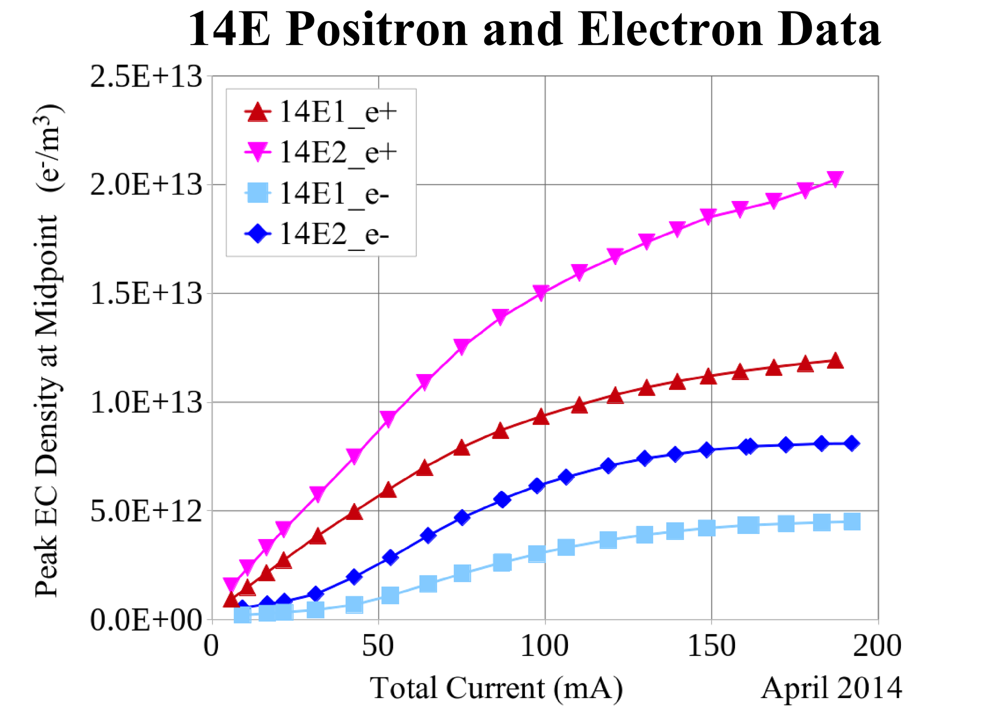
Dimensions in the 13-15E sector are used to calculate the expected resonant frequencies. The model is a shorted section of waveguide, with reflections produced at the longitudinal slots at ion pumps or transitions in beam-pipe geometry. The response at drive points 13-14E and 15E give a reasonable match to the measured response, but at 14E (right) the resonant series is not as simple.

Resonant Series $f^2=f_c^2+(nc/2L)^2$ with n the number of half wavelengths over the length L

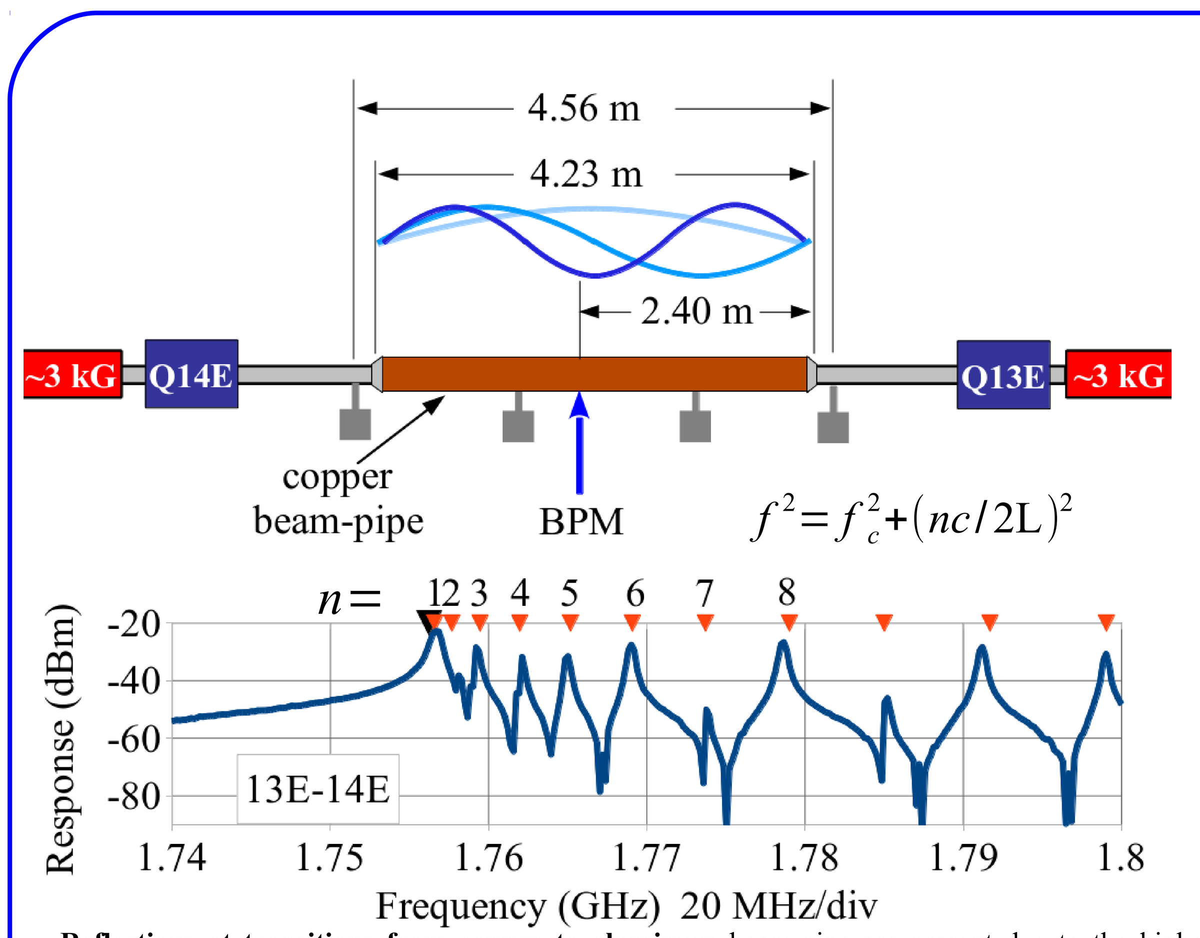


With drive/receive at 14E, a single length L does not give the observed resonant series. As a result it is difficult to know what length of vacuum chamber the standing waves occupy. The series for L = 9.86 and 5.64 are shown.

14E Positron and Electron Data

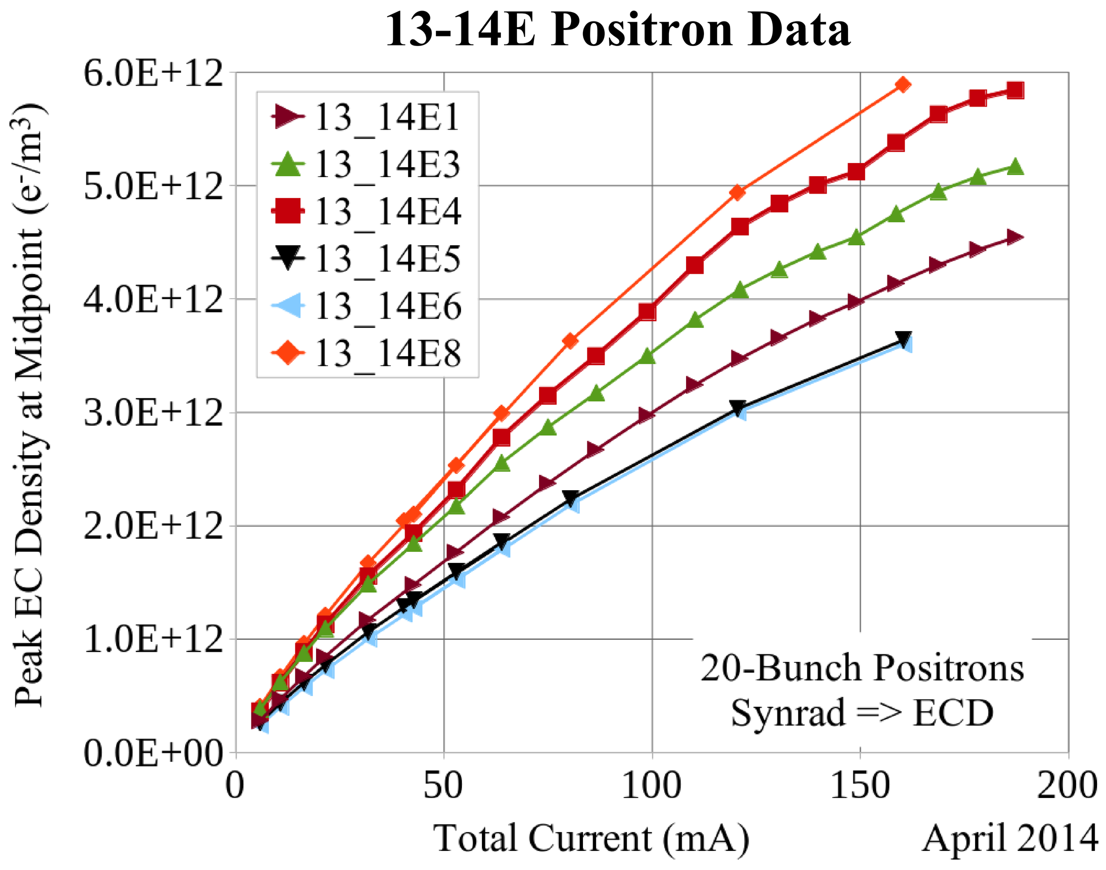


At 14E the two lowest resonances were used, 14E1 and 14E2. For both positrons and electrons, the EC density measured by 14E1 and 14E2 differ by about a factor of two. This needs further explanation.

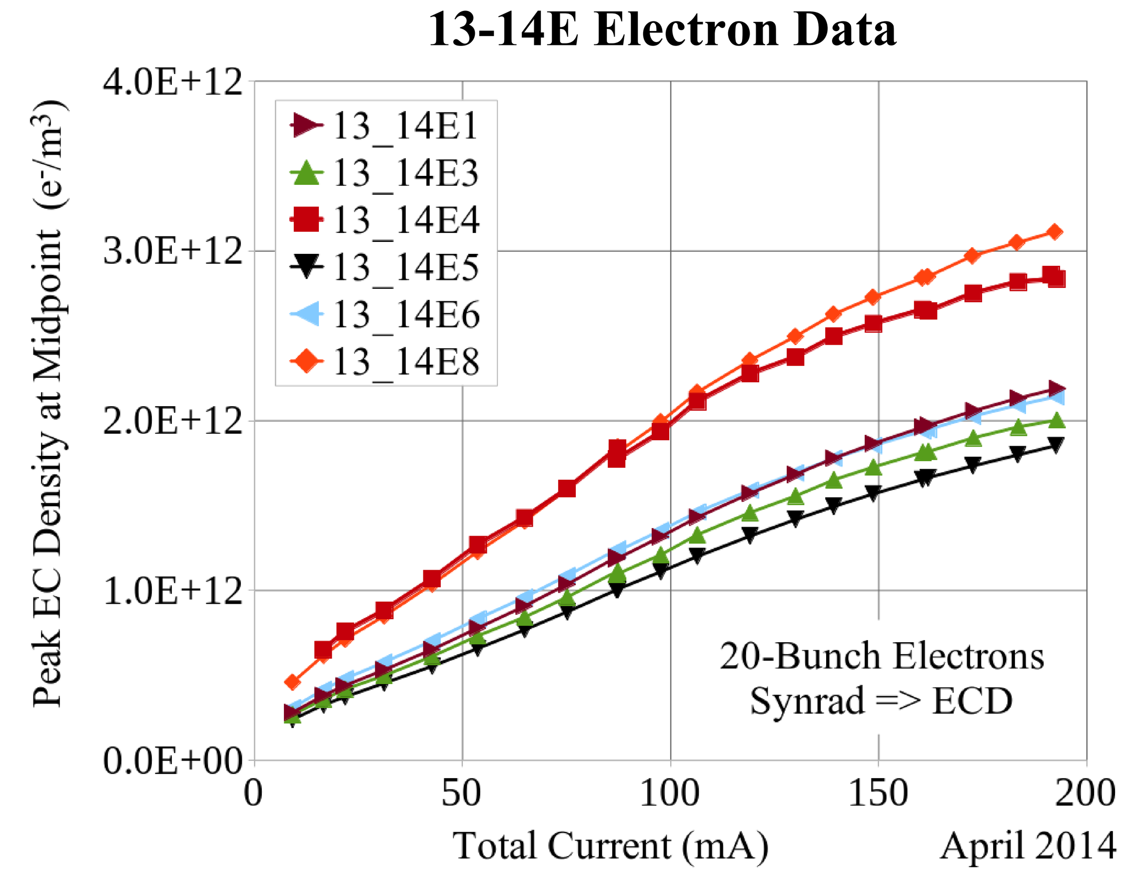


Reflections at transitions from copper to aluminum beam-pipe are present due to the higher cutoff frequency of the aluminum extrusion. In this case, the resonant series matches the calculation based on the cutoff frequency and the 4.23 m length of the copper section .

13-14E Positron Data



13-14E Electron Data



The 13-14E copper chamber shows a fairly linear EC density with beam current for both positron and electron beams. The EC density obtained for the different resonances varies by more than 50%. This suggests that there is something unaccounted for in the calculation of EC density.

*CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation PHY-0734867, PHY-1002467 and the US Department of Energy DE-FC02-08ER41538, DE-SC0006505.
† jps13@cornell.edu