PRIMARY PHOTOELECTRON MODELING FOR MEASUREMENTS WITH A SHIELDED BUTTON DETECTOR

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Cornell Electron Storage Ring Test Accelerator(CesrTA) is very similar to the proposed damping rings for the future International Linear Collider (ILC). For this reason, Cornell University has been doing extensive research for the ILC. A very important phenomena that deserves much attention is the electron cloud and how it will affect either the positron or electron beam. In order to better understand the electron cloud the primary photoelectrons that are creating the cloud must be studied. This paper will discuss the newfound phtotoelectron energy distributions for the electron and positron beams at 5.3 GeV and the electron beam at 2.1 GeV. These results were obtained using ECLOUD model and comparing the simulation results to the data gathered from the shielded buttons.

1. Introduction

The electron cloud will affect the tune and phase shifts along with other properties of the electron and positron beams. An accurate energy distribution enables more accurate modeling of the electron cloud. This would open up many other modeling opportunities for future work. The ECLOUD [1] simulation is able to track the energies of macroparticles which it can in turn use to calculate the electron cloud charge. For the proposed ILC, the electron cloud effects on both of the beams will be significant. An accurate model of the electron cloud would greatly assist in the research development for the ILC.

2. Experimental Setup

The primary setup for collecting data is called a Shielded Button Unit (SBU). The SBU contains three buttons at the top of the beam chamber.The buttons are behind a metal grating that is designed to only accept electrons entering perpendicular - or within 18 degrees to the normal - to the grating. The beam chamber is wrapped in wire that can induce a solenoidal magnetic field. The trajectories shown in Fig. 1 are for a solenoid field out of the page.The current entering the buttons will be measured; however, the energy of each of the individual electrons will not be measured.

3. Simulations

My major tool for coming up with the energy distributions for the various beams and energies was the two-dimensional modeling program ECLOUD and the Physics Analysis Workshop (PAW).The simulation required dozens of input parameters including the bunch

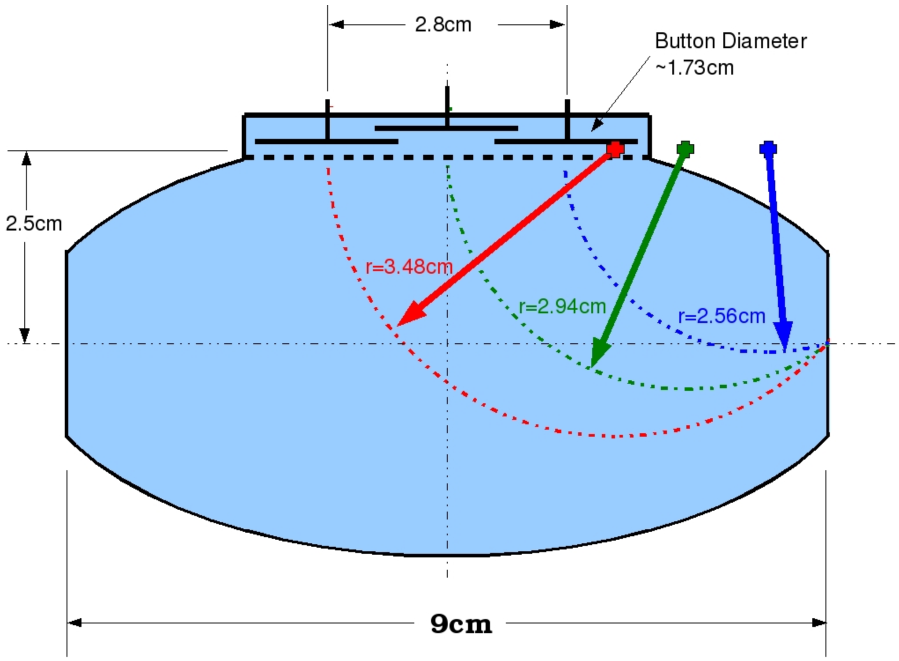

FIGURE 1. This is a 2D cut of the beam chamber showing the three buttons and the metal grating below them. The trajectories shown correspond to the path electrons would have to travel to enter perpendicular if the solenoid field were turned on.

current, number of macroparticles, solenoid field strength and reflectivity among many other parameters. The number of macroparticles could be increased in order to improve statistics or lowered to improve the amount of time it takes for the simulation to run. Reflectivity is a measure of how reflective the interior of the chamber is. A low percentage means that the majority of the light from the synchrotron radiation will create primary photoelectrons at the spot it strikes;whereas, a large percentage means that majority of light will be reflected somewhere down the chamber. For these simulations the reflected percentage was distributed evenly around the chamber. The reflectivity was set at 33% for the electron beam and at 20% for the positron beam at 5.3 GeV. The reflectivity for the 2.1 GeV electron beam will be explained later.

I was primarily focused on the primary photoelectron distribution which took three input parameters. The numbers are entered in the following sequence: -E_{max} p_1 p_2. The dash does not imply a negative energy, it is simply a switch to let the program know to use the new distributions. These numbers are plugged into Eq. (1) to create a distribution for the primary electrons.

$$f(E) = \frac{E^{p_1}}{(1 + \frac{E}{E_o})^{p_2}} \tag{1}$$

where

$$E_o = \frac{E_{max}(p_2 - p1)}{p_1}. \tag{2}$$

Prior to this new implementation, a low energy Gaussian distribution was used for both the electron and positron beam at 5.3 GeV and the electron beam at 2.1 GeV. The old distribution was found to be wrong for all.

4. Results

4.1. **Difference in Electron and Positron Beams.** The electron beam affects low energy electrons inside the electron cloud differently than the positron beam. Due to coulombic repulsion, an electron bunch of 18 mm rms length carrying 1.3×10^{10} electrons (8 mA) will suppress all photoelectrons with energies below approximately 50 eV. Along with completely suppressing the low energy photoelectrons, the beam kick will push the the higher energies photoelectrons back towards the wall effectively lowering their energy. Fig. 2 shows how the beam will affect the arrival energy of the photoelectrons.

Due to the effects of coulombic attraction, the positron beam interacts very differently with the photoelectrons. The beam kick will attract the primaries and in turn increase their energy. The beam has a large effect on low energy photoelectrons so the (add more)

Another difference in the signal shape also comes from the difference in how the beams interact with the photoelectrons. The electron beam will push most low energy primaries back into the chamber wall which will have no effect on the signal shape, but, due to reflectivity, some of the primaries are formed on the grating below the buttons. The beam kick will push these electrons back into buttons causing a small peak very early in the signal. See Fig. 4. The primary photoelectron energy parameters I concluded worked well were : -20 0.18 4.0. Fig. 4 shows the comparison between the simulated signal and data.

Critical energy is defined as being the energy for which there is an equal amount of photons above and below that value. The critical energy is dependent on the gamma factor and the bending radius of the beam as follows

$$E_c = \hbar c \frac{3\gamma^3}{2\rho} \tag{3}$$

where ρ is the bending radius. For a 5.3 GeV beam the equation can be simplified to

$$E_c = \frac{330 \text{ keV}}{\rho}. \tag{4}$$

The synchrotron radiation source is in a magnet. They have different bending radii with the positron beam having a bending radius approximately a factor of 3 times larger than that of the electron beam. The critical energy is 3667 eV for the positron beam and 5500 eV for the electron beam. This also means that the primary electrons for the two beams

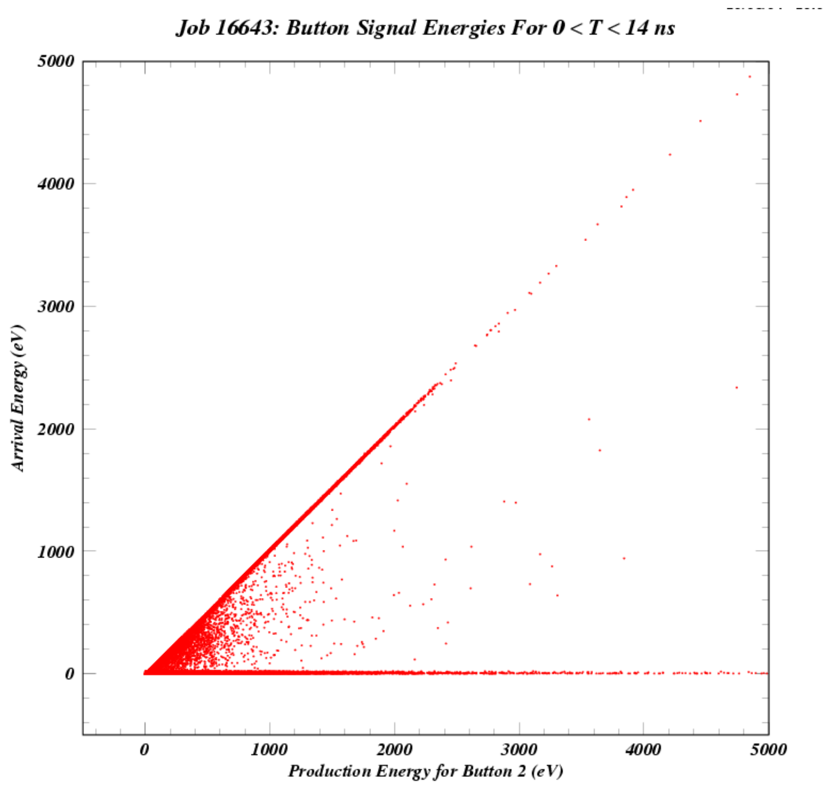

FIGURE 2. Arrival Energy Vs. Production Energy for cloud particles contributing to the shielded button signals for an electron beam. Many of the photoelectrons arrive with an energy lower than that with which they were produced because the beam kick lowers their energy. Some of the photoelectrons have a very low arrival energy even though they have a high production energy because they collided with the wall and lost most of their energy before they got to one of the buttons.

will have different energy distributions. The ED for the positron beam will have much lower primary electrons compared to those created by the electron beam. Taking this into account, I found the ED for the positron beam to be: -12 0.8 4.5. See Fig. 5.

4.2. **Effect of Bunch Current on Signal.** The electron beam bunch population has little effect on the peak signal time. Fig. 6 shows the growth in signal strength as the current increases. This result is counterintuitive because a stronger current would produce a stronger beam kick which would lower the energy of the photoelectrons and thus result in a later peak signal. However, both the data and simulation show that the peak signal time does not change as the current changes. One explanation is that the electron beam is only suppressing photoelectrons low enough in energy that they wouldn't have an effect

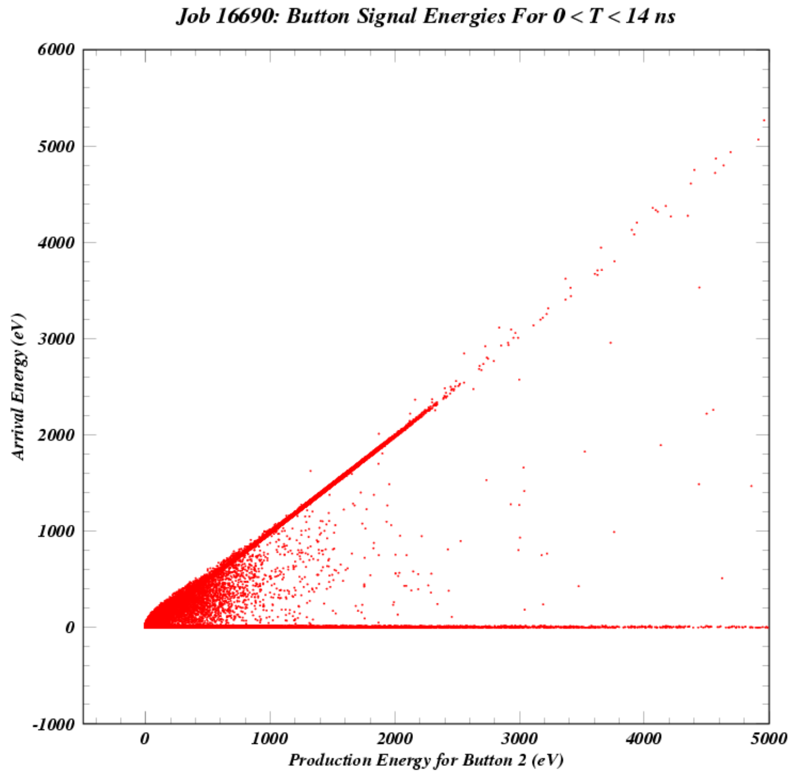

FIGURE 3. Arrival Energy Vs. Production Energy for a positron beam. Many of the photoelectrons will have a higher arrival energy than production energy because the beam kick will attract them away from the wall.

on the signal whereas the beam has very little effect on the higher energy primaries which, for the most part, determine the beam shape. The growth in peak signal strength occurs as the beam current grows because a higher current produces more synchrotron radiation which in turn create more photoelectrons.

The current of the positron beam has a significant effect on the signal. As was discussed in Section 3.1, the energy distribution for the positron beam has many low energy primaries so the beam kick has a big effect on the primaries and the resultant signal shape. An increase in the bunch current directly results in an earlier peak time. See Fig. 7.

4.3. **Effects of Magnetic Field on Signal.** When the magnetic field is off, the signal is made up of the electrons that are traveling from the bottom of the vacuum chamber up to the buttons and the electrons formed on the side walls have very little effect on the signal. For solenoid-on data and simulations, the signal initially depends heavily on the electrons formed on the outside wall because electrons formed on the floor will be pushed towards the inside wall. Fig. 8 shows the asymmetry in the electron cloud caused by a

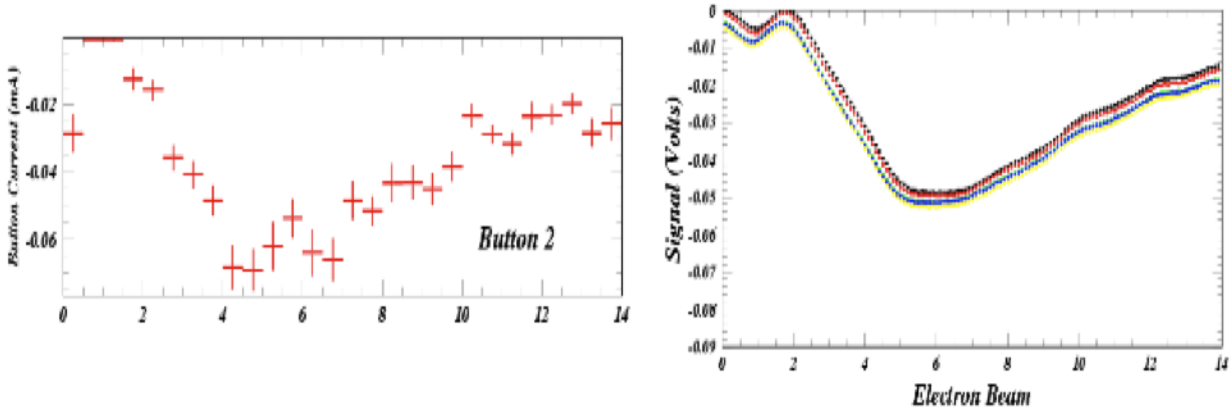

Figure 4. Button Current Vs. Time (ns) for an electron beam. The simulation is on the left and the data is on the right. The simulation shows consistent results. Note the very prompt signal which is caused by beam kicking low-energy photoelectrons formed near the buttons back into the buttons.

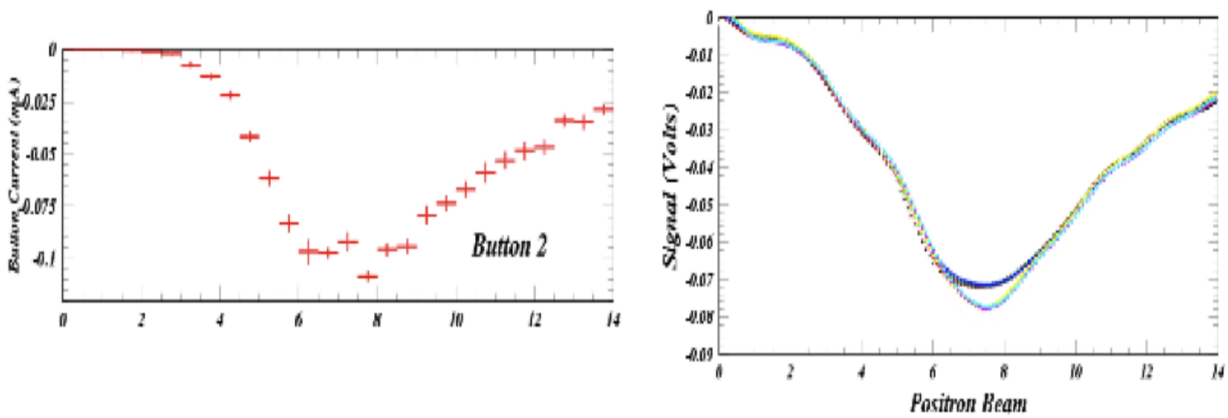

Figure 5. Button Current Vs. Time (ns) for a positron beam. The simulation shows consistent results once the ED has been adjusted.

20 Gauss field. The solenoid-on data is dependent on photoelectrons with certain energies and certain trajectories. The radius an electron will travel can be found by starting out with the Lorentz Force and Centripetal Force set equal and solving for the velocity yields

$$v = \frac{qBr}{m}. \tag{5}$$

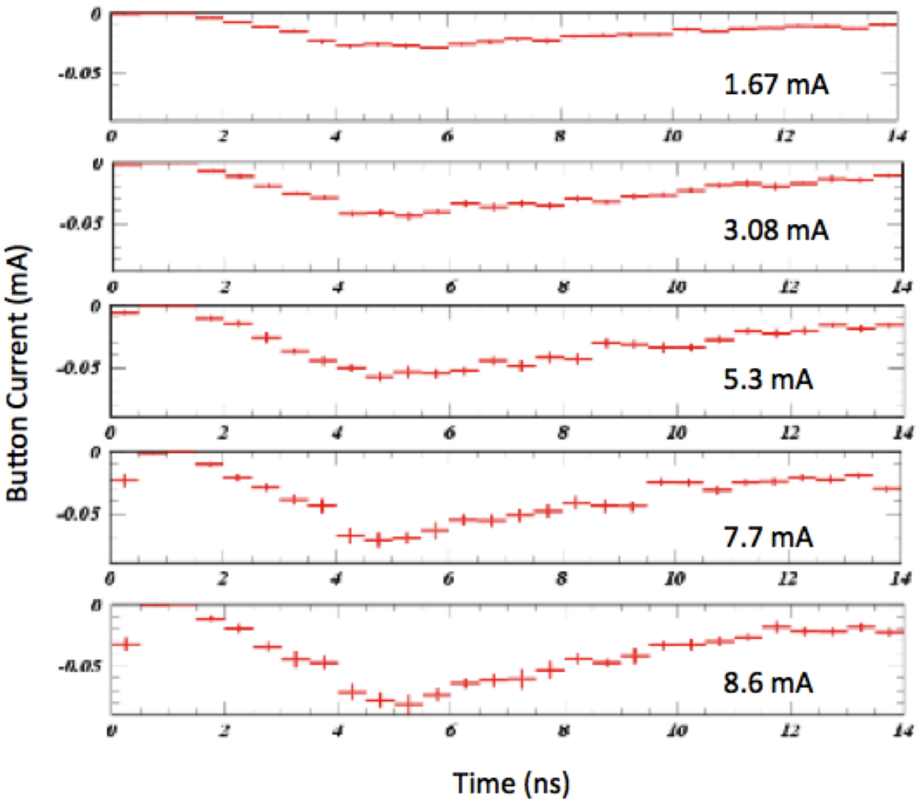

FIGURE 6. Simulation results for various bunch currents with an electron beam. A single bunch arrives at t=0 s. Note that the signal becomes stronger as the current grows but the peak signal time occurs at the same time.

The electrons are low enough in energy that relativity does not have to be taken into account; plugging Eq. (5) into the kinetic energy equation yields

$$E = \frac{1}{2}\frac{q^2}{m}(B^2r^2) \tag{6}$$

which can be simplified to

$$E_{ev} = 8.7941 \times 10^{10}(B^2r^2) \tag{7}$$

with the energy in units eV, B in units of Tesla's, and r in units of meters. Using the radii from Fig. 1 and 0.002 Tesla (20 G) for the field strength, one finds the required energy for the centers of the buttons buttons, from right to left, is 230 (Button 1), 304 (Button 2), and 426 (Button 3) eV. These values can be compared to the simulated energy values for an electron beam of each of the buttons shown in Fig. 9. The simulated values are for the optimized ED (sect. 4.2) of: -20 0.18 4.0. These parameters were also used for the

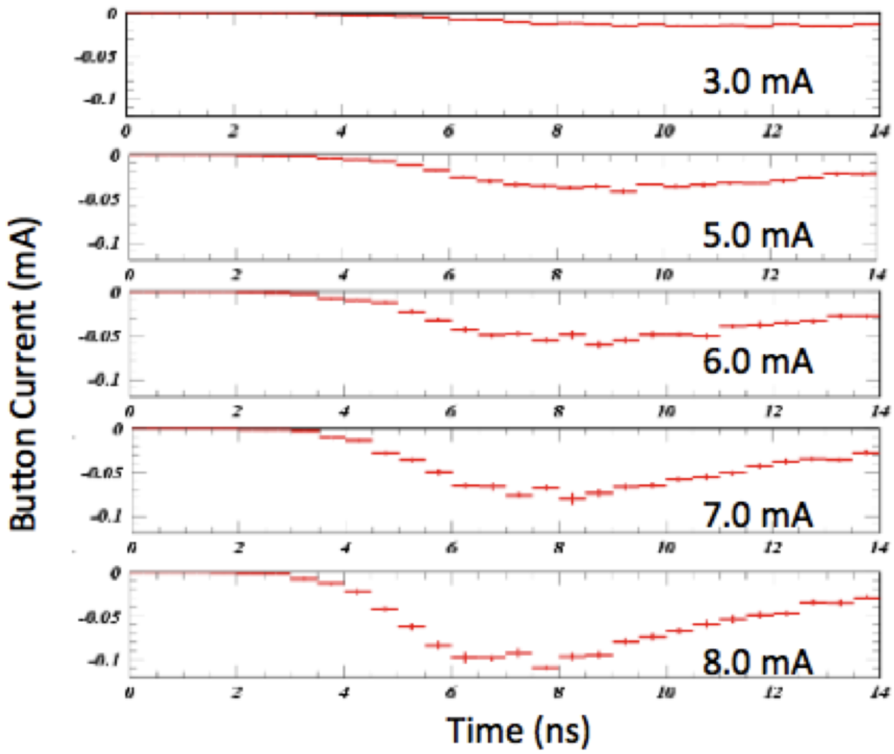

FIGURE 7. Simulation results for various bunch currents with a positron beam. A single bunch arrives at t=0 ns. The bunch current has an effect on the much lower energy electrons in the positron beam ED which is very different for the electron beam. As the bunch current increases the signal arrives noticeably earlier.

solenoid-off data for an electron beam. Fig 10 shows the comparison between simulation and data for the electron beam with a 20 Gauss solenoid field. The positron beam required a different ED for the solenoid-on simulations than for the solenoid-off. The reasons for this will be discussed in the next section. The ED for the positron beam was: -25 0.2 3.5. Fig. 11 shows simulation and data comparisons.

4.4. **Difference in Solenoid-Off and Solenoid-On ED for Positron Beam.** The ED for the positron beam had to be reconfigured for solenoid-on simulations. It was found that the signal arrived a almost two ns late when the previous energy distribution was used. The new primary energy distribution will require higher energy photoelectrons. The same ED produced good results for both solenoid-off and solenoid-on data for the electron beam but it was not necessarily anticipated to work for the positron beam because, as was discussed earlier, for solenoid-on data most of the signal comes from photoelectrons

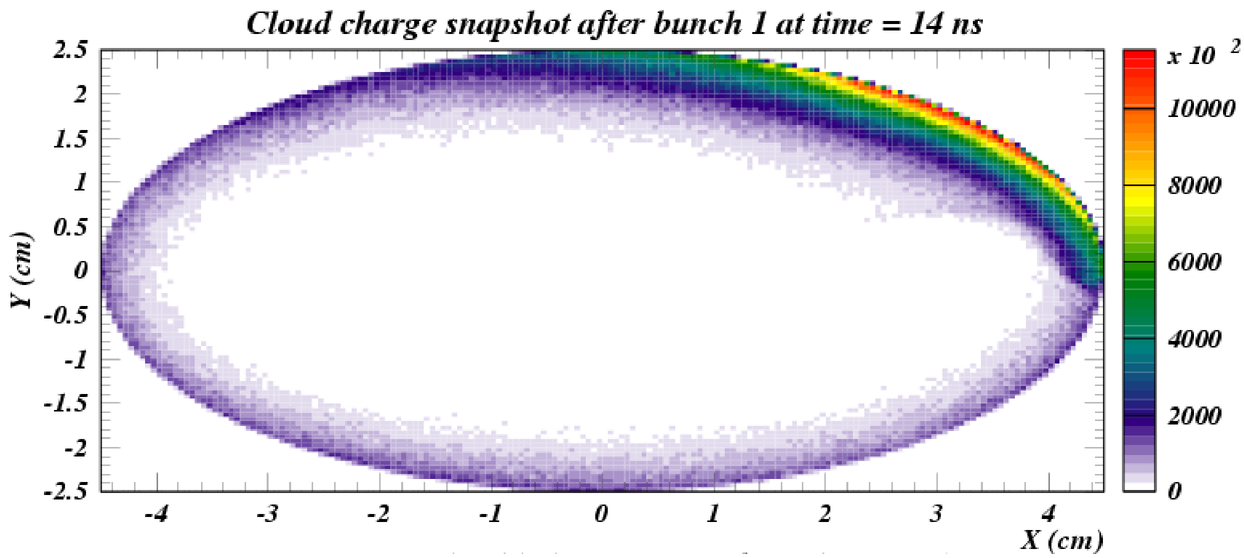

FIGURE 8. The electron cloud charge for a 20 Gauss solenoid field 14 ns after the first bunch. This is the space charge that the second bunch will see. Note the asymmetry in the cloud charge caused by the solenoid field.

produced on the wall of the chamber. For the solenoid off data the positron beam peak signal arrived approximately 3 ns later than the electron beam peak so the energy needed to be much lower (work on this)

4.5. **Energy Distribution and Electron Cloud Density Plots.** The only way to accurately see the number of photoelectrons produced at each energy was to look at the primary photoelectron energy distribution plots. As has already been discussed, the energy distributions for the electron and positron beam at 5.3 GeV are different. The three input parameters do not make it easy for one to grasp the difference in the energy distributions. Fig. 12 shows the comparisons between 5.3 GeV electron and positron beam energy distributions. However, these energies are not fully accurate because the electron beam will lower the energy of the photoelectrons whereas the positron beam will increase the energy of the photoelectrons. It is not known what the exact energy distribution would look like right after the beam kick has changed the energies of the photoelectrons, but based on the signal shapes for the solenoid-off data, the energy distribution for the photoelectrons formed by the positron beam must still be lower than those from the electron beam.

4.6. **Energy Distribution for Low Energy Beam.** As was shown in Eq. (3), the critical energy of the beam is dependent on γ^3 therefore lowering the energy of the beam from 5.3 GeV to 2.1 GeV will very much change the critical energies for each of the beams. The critical energy for the electron beam at 2.1 GeV is 340 eV. A different primary photoelectron

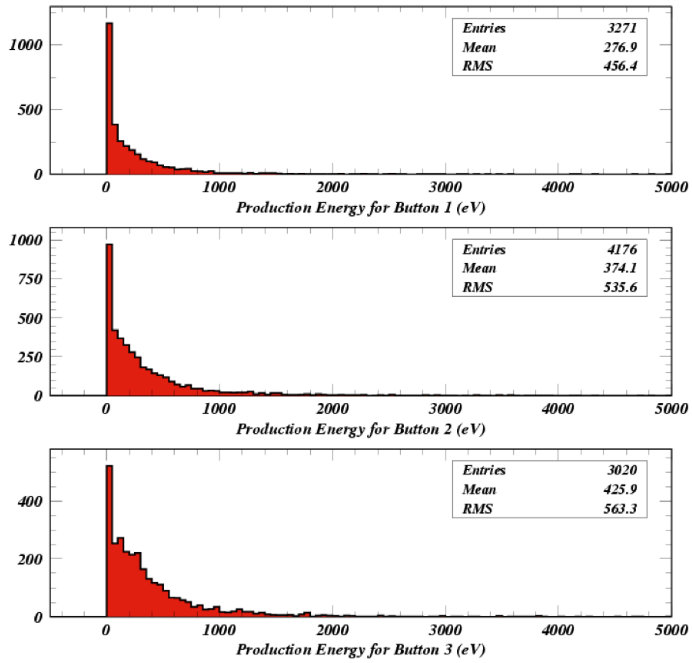

FIGURE 9. Production Energy for an electron beam of primary photoelectrons for each of the three buttons. Each of the buttons accepts a range of energies but the mean values are close to the predicted values.

energy distribution is required for the 2.1 GeV electron beam. Data was only available for the electron beam at 2.1 GeV so that was the one I focused on.

The ED was determined using solenoid-on data because solenoid-off data showed no discernible signal. However, not all solenoid-on data was useful since data with a magnetic field below 15 Gauss and above 25 Gauss had indiscernible signals as well. The fact that there was no discernible signal for stronger magnetic fields meant that the photoelectron energies were lower than required for electrons coming from the side wall to get into the buttons for a 40 Gauss magnetic field. In order to find an ED that had a reasonably consistent signal shape, the reflectivity had to be turned off otherwise there is too much contribution to the signal from other parts of the chamber. The ED that was decided on was : -5 0.2 5.0. Fig. 13 shows the results of these values.

5. Conclusion

Prior to the start of this project the same energy distribution was used for the electron and positron beams at 5.3 GeV and for the 2.1 GeV electron beam. This energy distribution was 5 eV Gaussian that contained too few high energy photoelectrons. A very useful tool for finding energy distributions that worked was the shielded button data taken by John Sikora. The shielded buttons signals could be compared to the simulation results to find the

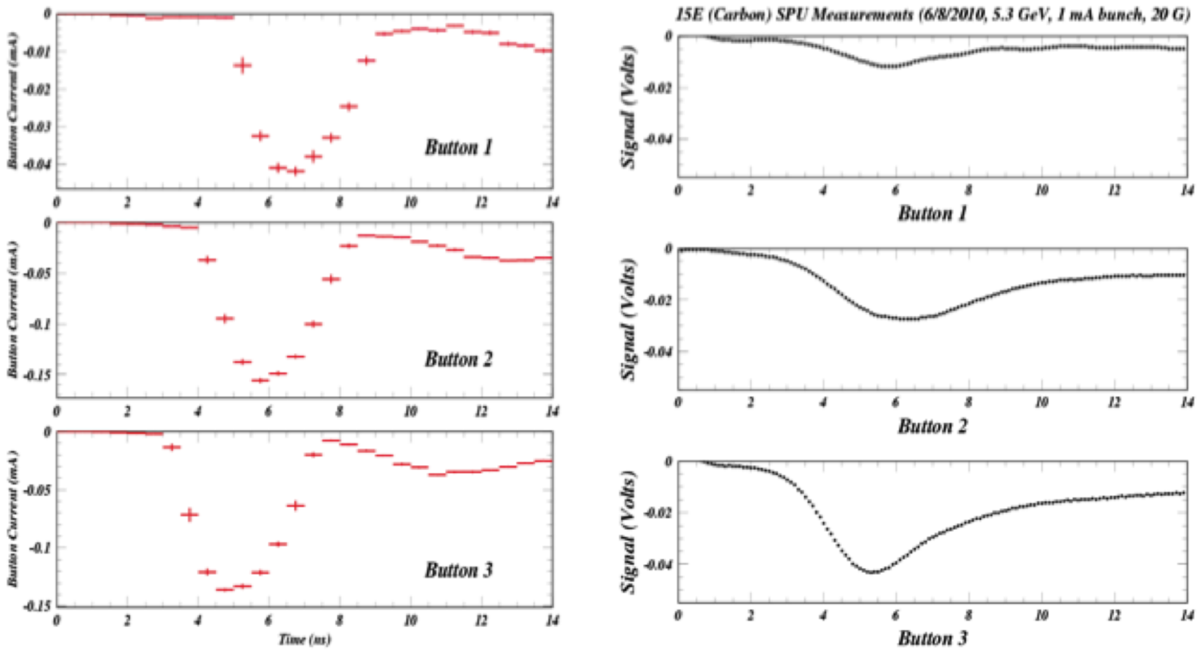

Figure 10. Comparison of simulation and data for electron beam with 20 Gauss solenoid field.

correct energy distributions. The new energy distribution also provided a lot of information about the reflectivity. Lastly, and most importantly, the new ED's will allow for much more accurate modeling of the electron cloud and its effects.

6. Acknowledgements

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References

[1] F. Zimmermann and G. Rumolo, Electron Cloud Effects in Accelerators, ICFA Beam Dynamics Newsletter No. 33, eds. K. Ohmi and M.A. Furman (2004)

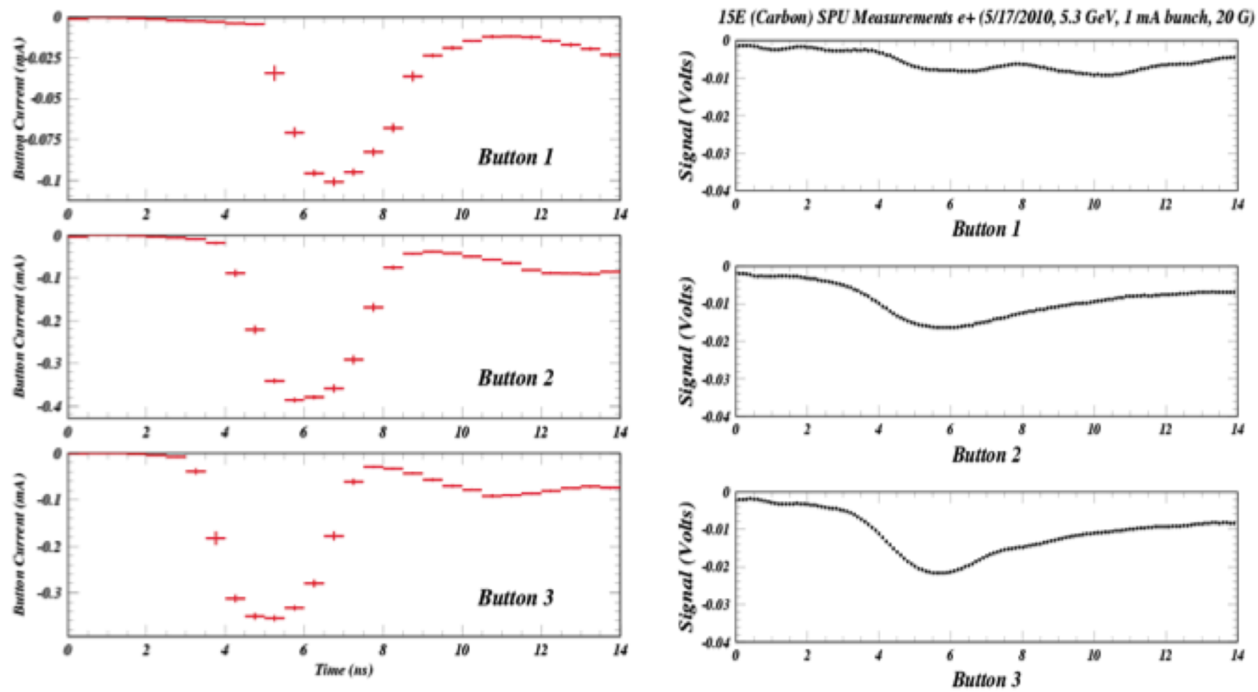

FIGURE 11. Comparison of simulation and data for positron beam with 20 Gauss solenoid field.

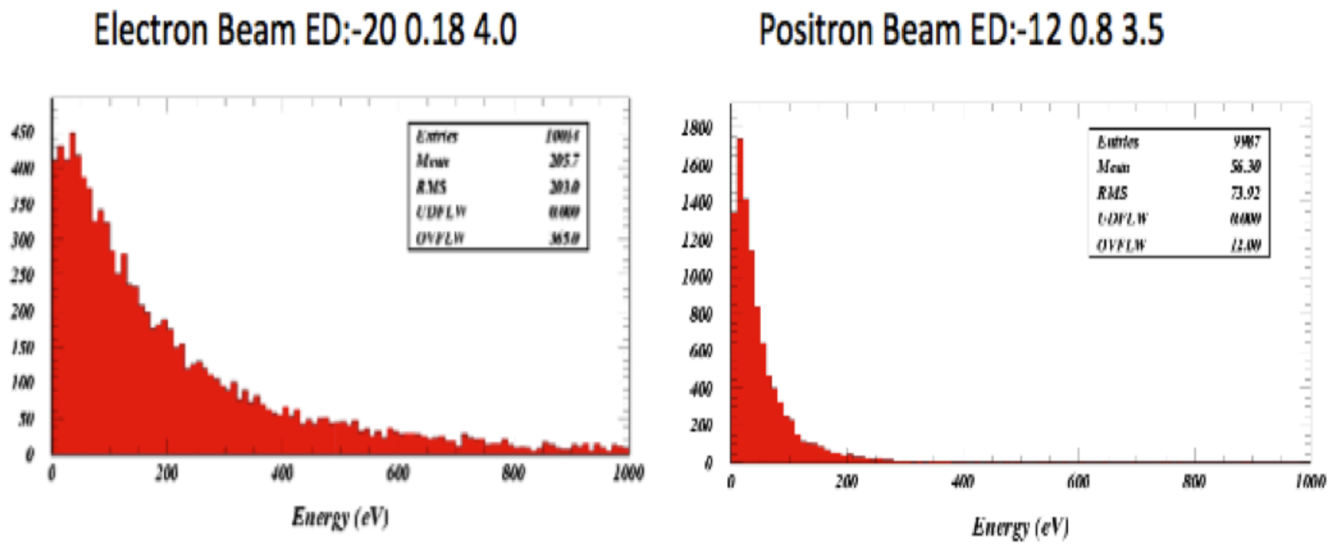

FIGURE 12. These are energy distribution plots for the electron and positron beam for solenoid field off. This is the distribution used by the ECLOUD model. Note the much higher energies for the electron beam.

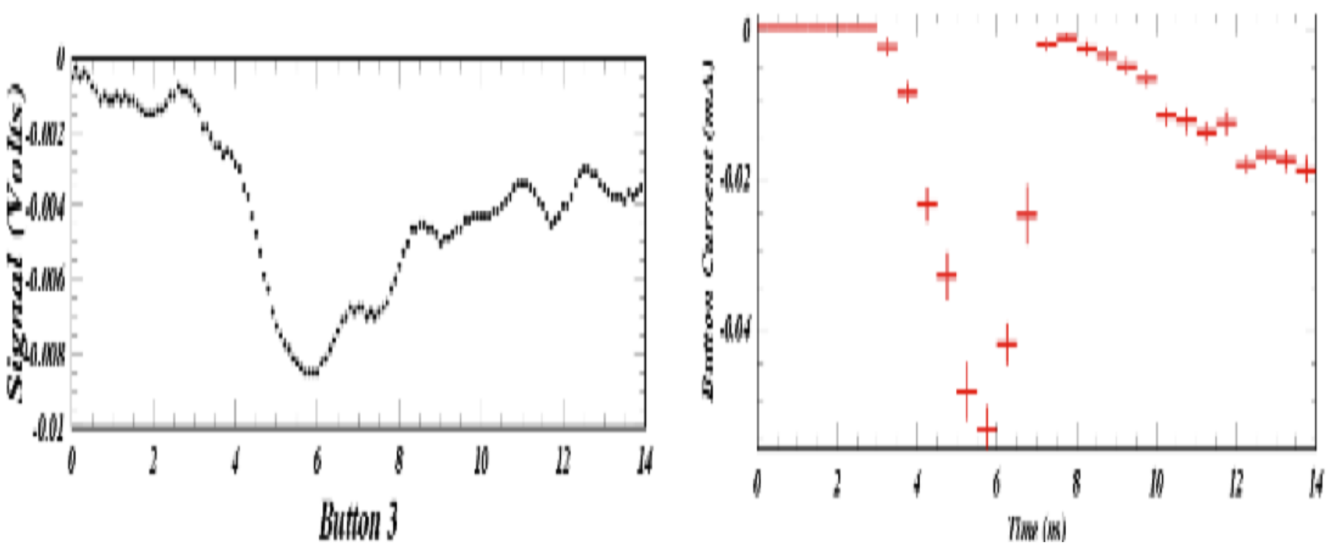

FIGURE 13. Signal comparison for 2.1 GeV electron beam for magnetic field of 20 G. The agreement is reasonable but is only achieved after the reflectivity has been set to 0%.