

Electron Cloud Modeling Results for Time-Resolved Shielded Pickup Measurements at CEsrTA

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Abstract

The Cornell Electron Storage Ring Test Accelerator (CsTA) program includes investigations into electron cloud buildup, applying various mitigation techniques in custom vacuum chambers. Among these are two 1.1-m-long sections located symmetrically in the east and west arc regions. These chambers are equipped with pickup detectors shielded against the direct beam-induced signal. Here we report on results from the ECLLOUD modeling code which highlight the sensitivity of these measurements to model parameters such as the photoelectron energy distributions, and the secondary elastic yield value.

INTRODUCTION

The CsTA program [1] includes the installation of custom vacuum chambers with retarding-field-analyzer (RFA) ports and shielded-pickup (SPU) detectors [2, 3]. The time-resolved measurements from the SPU detectors provide time structure information on cloud development, in contrast to the time-integrated RFA measurements [4].

SENSITIVITY TO THE PHOTOELECTRON ENERGY DISTRIBUTION

The upper row of Fig. 1 shows examples of SPU signals for two bunches of 5.3 GeV positrons and electrons separated by 14 ns. The population of the first bunch is 1.3×10^{11} , while that of the trailing bunch varies up to a similar value. The trailing bunch accelerates cloud particles into the detector, producing the second signal. The arrival time and structure of the earlier signal corresponds to photoelectrons produced at the time of bunch passage on the lower chamber wall. The kick from the positron bunch accelerates such photoelectrons toward the detector, whereas in the case of an electron beam the signal electrons must carry sufficient kinetic energy to overcome the repulsion of the beam bunch.

The lower row of Fig. 1 shows an initial attempt to model the case of two bunches of population 1.3×10^{11} using the electron cloud simulation code ECLLOUD [5]. The calculation of cloud kinematics including space charge forces

and beam kicks determines arrival times, momentum vectors and charges of the macroparticles reaching the upper surface of the chamber at the locations of the pickups. This early attempt at simulating the observed signals included a rather crude model of the SPU acceptance, leading to poor approximation of the magnitude of the signal, but it was sufficient to diagnose the obvious discrepancy with the observed signals. The positron case shows moderate time structure differences, but the modeling of the electron beam kick exhibits a dramatic discrepancy. The arrival times of the observed signals correspond to photoelectrons produced on the lower wall of the chamber, which is effected in the simulation via a reflectivity parameter distributing 20% of the photoelectrons uniformly in azimuth. The prompt signal from each electron bunch corresponds to photoelectrons produced on the upper wall repelled into the detector during the bunch passage. The photoelectrons produced on the lower wall in the ECLLOUD simulation are similarly reabsorbed, and these are the ones needed to produce the observed signal! In other words, the measurement shows that photoelectrons of sufficient energy to overcome the repulsion of the beam bunch must be present. The photoelectron energy distribution in this original default model is common to many successful simulations of a wide variety of experimental observations [5, 6, 7, 8], namely a Gaussian with average and rms values of 5 eV limited by truncation to positive values. The SPU measurements are thus providing unique sensitivity to the high-energy portion of the photoelectron energy spectrum. A description of the power-law parameterization which matches the data can be found in Ref. [3]. A similar study for the case of a 2.1-GeV positron beam, where the critical energy of the incident radiation is 230 eV rather than 5.6 keV, found that a Lorentzian with a peak energy of 5 eV and a width of 7 eV reproduces the measured signal shape significantly better than the 5-eV Gaussian.

CLOUD LIFETIME STUDIES USING WITNESS BUNCHES

The witness bunch experimental method consists of generating a cloud with a leading bunch, then accelerating cloud electrons into the SPU detector with a trailing bunch at various delay times. The mature cloud long after passage of any beam bunch is dominated by low-energy secondary electrons which suffer predominantly elastic interactions

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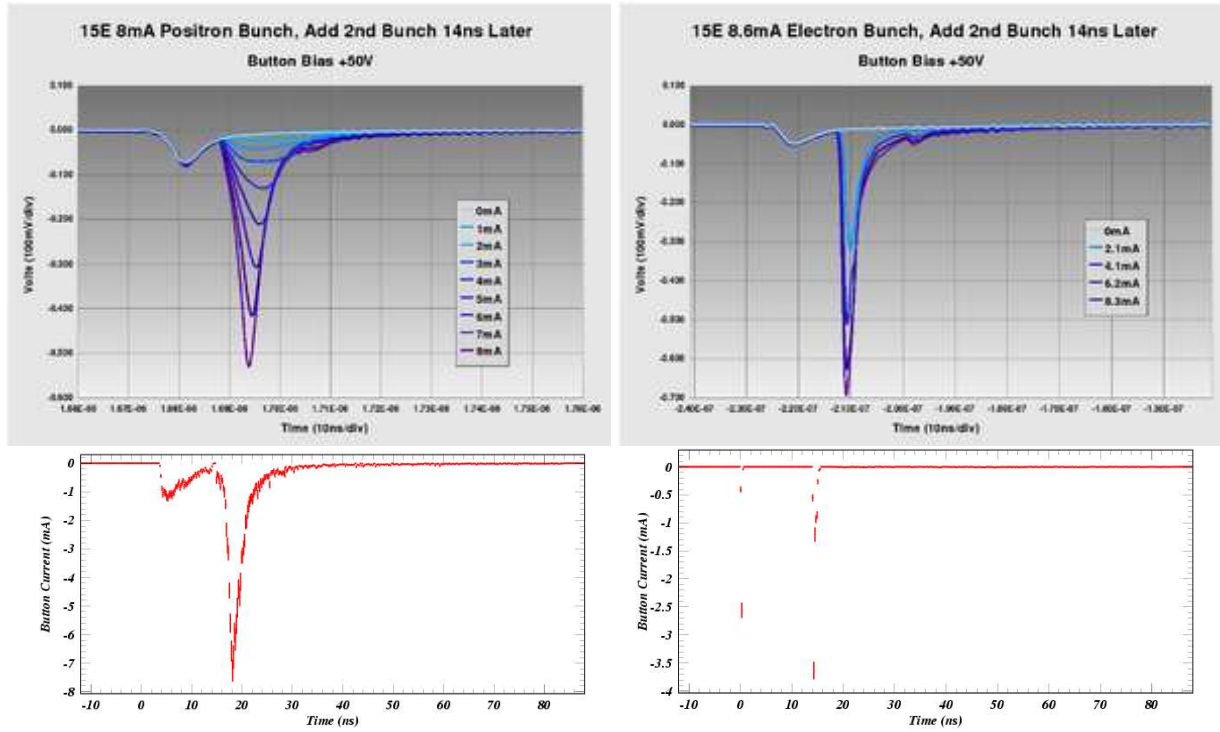


Figure 1: Upper row: shielded-pickup signals produced by two 5.3 GeV positron (left) and electron (right) bunches separated by 14 ns. Lower row: initial ELOUD model results exhibiting discrepancies with the measured signals which are quite dramatic in the case of the electron beam.

with the vacuum chamber wall, determining the decay time of the cloud density, typically of order 100 ns. The elastic yield parameter δ_0 describes the ratio of outgoing to incoming macroparticle charge in probabilistic models [10]. Cloud electrons with energy greater than 100 eV, produced by synchrotron radiation, beam kicks, or the rediffused component of the secondary yield process, undergo primarily the true secondary yield process, in which the produced secondary carries only a few electron volts of kinetic energy, resulting in the dominance of low-energy electrons late in the cloud decay. A phenomenological investigation with sensitivity to the elastic yield has also been performed at RHIC [9].

The magnitude and time structure of the signal from the leading bunch is determined by the reflective properties of the vacuum chamber and by the energy-dependent quantum efficiency, as described in the preceding section. The signal induced by the witness bunch has an additional contribution from the acceleration of existing cloud electrons into the detector. The latter contribution is sensitive to the cloud density and the spatial and kinematic distributions of the cloud electrons. Figure 2 shows the results of six sets of simulations with various values for the elastic yield parameter δ_0 . In each of the six plots, six two-bunch (5.3 GeV, 8×10^{10} positrons each) pickup signals are superposed, whereby the delay of the witness bunch varies from 14 to 84 ns. For this titanium-nitride-coated aluminum chamber (TiN), a peak secondary yield of 0.8 at a peak energy of 400 eV was assumed. The modeled signals are shown with sta-

tistical error bars corresponding to the number of contributing macroparticles. The magnitudes of the modeled signals at large witness bunch delay clearly show the dependence on the elastic yield parameter δ_0 as it is varied from 0.05 to 0.75. The best description of the measured signals is given by a value $\delta_0 = 0.05$. This analysis method has also been applied to an uncoated aluminum chamber, yielding an optimal value $\delta_0 = 0.75$. This value can be compared to the value $\delta_0 = 0.5$ used in the modeling of CsrTA coherent tune shift measurements [6, 7, 8], where the measurements are much less sensitive to δ_0 . These studies have been performed for a carbon-coated aluminum chamber [11, 12] as well, where the elastic yield was found to be 0.05, similar to the value found for the TiN coating.

Many systematic studies are underway, discovering sensitivity to many detailed characteristics of the cloud. For example, the signal widths for early witness signals depend strongly on the azimuthal production distribution of photoelectrons, as was observed by implementing in ELOUD the distributions calculated by the photon-tracking reflectivity model for the CESR ring described in Ref. [13]. These systematic studies have not changed the quantitative conclusions concerning the sensitivity to δ_0 . Generally one can say that the choice of peak secondary yield value relative to the effective reflectivity value determines the ratio of the early witness bunch signal magnitudes to that from the leading bunch. For witness bunches late enough that the signal magnitude becomes comparable to that of the leading bunch, there is little sensitivity to the true or rediffused

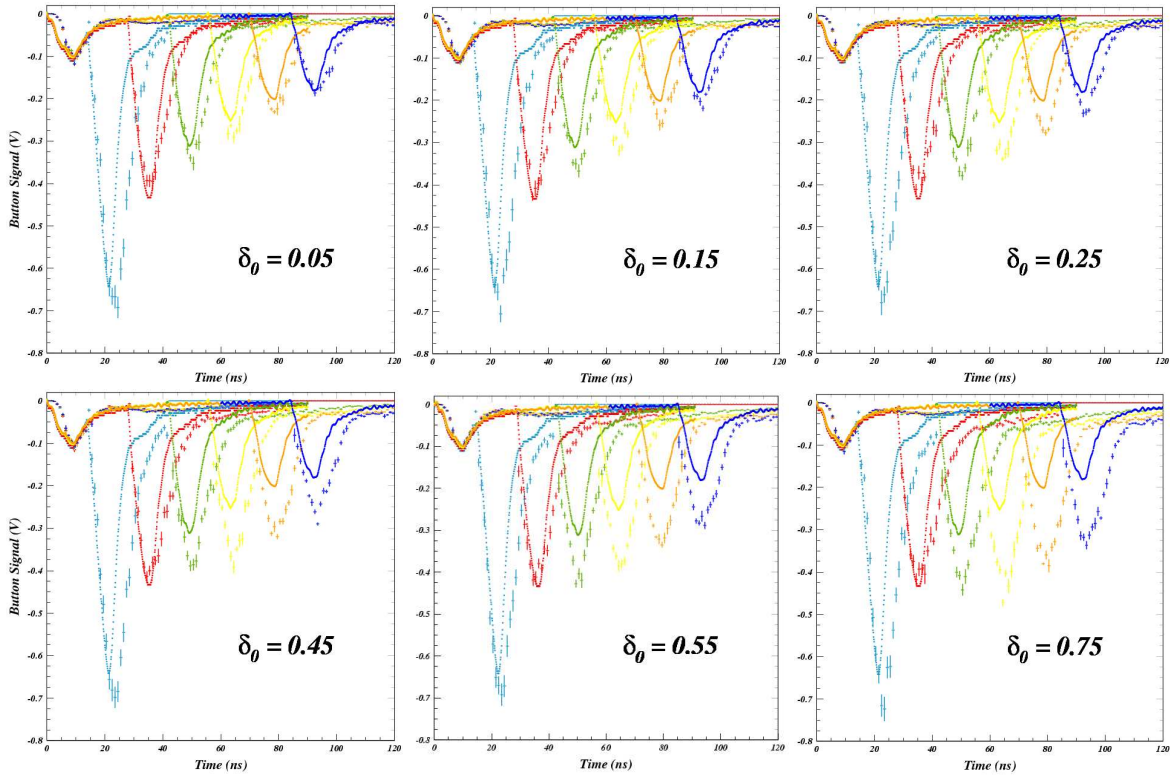


Figure 2: Witness bunch study with the TiN-coated aluminum chamber.

secondary yield. Instead, those signal magnitudes are determined by the value for the elastic yield.

SUMMARY

The CEsTA shielded-pickup detectors provide a wide variety of time-resolved measurements of electron-cloud-induced signals. Measurements with custom vacuum chambers incorporating cloud mitigation techniques such as amorphous carbon and TiN coatings have been compared to the those obtained with an uncoated aluminum chamber. A model for the shielded pickup acceptance has been developed in the context of the electron cloud simulation code ECLOUD. The shielded pickup data have proved remarkably sensitive to model parameters poorly constrained by any other experimental means, such as the azimuthal production distribution for photoelectrons and their energy distributions. The measurements with 5.3 GeV electron and positron beams indicate the need for a high-energy component previously absent in the photoelectron generation model. In addition, the design purpose of the shielded pickup detectors has been experimentally confirmed, as the cloud lifetime has been accurately measured using witness bunches at various delays. Sensitivity to the elastic yield parameter in the secondary yield model has been shown to be less than 0.05 and remarkably robust against variation of other model parameters. Data taken with a TiN coating provide a best estimate for the elastic yield of about 0.05. A similar cloud lifetime study in an uncoated aluminum chamber aluminum chamber, yielded

a value of 0.75, while results from an amorphous-carbon coating showed an elastic yield similar to that measured for the TiN-coating.

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