METHODS FOR QUANTITATIVE INTERPRETATION OF RETARDING FIELD ANALYZER DATA*

J.R. Calvey, J.A. Crittenden, G.F. Dugan, M.A. Palmer, CLASSE, Cornell University, Ithaca, NY, USA
K. Harkay, ANL, Argonne, Il, USA †
M. Venturini, LBNL, Berkeley, CA, USA

Abstract

A great deal of Retarding Field Analyzer (RFA) data has been taken as part of the CesrTA program at Cornell. Obtaining a quantitative understanding of this data requires use of cloud simulation programs, as well as a detailed model of the RFA itself. In a drift region, the RFA can be modeled by postprocessing the output of a simulation code, and one can obtain best fit values for important simulation parameters using a systematic method to improve agreement between data and simulation.

INTRODUCTION

In principle, a single RFA measurement gives a great deal of information about the local behavior of the electron cloud. A typical "voltage scan," in which the retarding voltage of the RFA is varied while beam conditions are held fixed, is a measurement of the density, energy distribution, and transverse structure of the cloud. In practice, however, it is a highly nontrivial task to map a data point from a voltage scan to any of these physical quantities. Typically, this gap is bridged through the use of cloud simulation programs, which track the motion of cloud particles during and after the passage of a bunch train. At CesrTA we have primarily used two such programs, POSINST [2] and ECLOUD [3].

The simplest method for simulating the output of an RFA for a given set of beam conditions is post-processing the output of one of these programs. More specifically, these codes can output a file containing information on each macroparticle-wall collision, and one can perform a series of calculations on this output to determine what the RFA would have seen had one been present. Note that by proceeding in this way one impicitly assumes that the presence of the RFA has no effect on the development of the cloud. This assumption is probably justified for a drift RFA, but may not be in the presence of a magnetic field [5]. This paper will focus on the drift case.

METHODOLOGY

The sheer volume of RFA data obtained so far at CesrTA necessitates a systematic method for detailed analysis. The goal is, given a set of voltage scan data, to find a set of simulation parameters that bring data and simulation into as close agreement as much as possible. The best fit parameters obtained from this method should be close to the real values for the material under study. The following method was employed to accomplish this:

1. Choose a set of voltage scan data.
2. Choose a set of simulation parameters.
3. Do a simulation with the nominal values of each parameter.
4. Postprocess the output of the simulation to obtain a predicted RFA signal.
5. For each data set and each parameter, do a simulation with a high and low value of the parameter, and determine the predicted RFA signals.
6. For each point in the simulated voltage scan, do a best linear fit to the curve of RFA signal vs parameter value. The slope of this line determines how strongly this point depends on the parameter.
7. Find a set of new parameters that should minimize the difference between data and simulation, assuming linear dependence of each voltage scan point on each parameter.
8. Repeat the process with this new set of parameters.

Table 1 lists one set of beam conditions that has been subjected to this method. All of these data were taken on the same day, at a beam energy of 5.3GeV. Note that it includes 20 and 45 bunch trains at different bunch currents, as well as 9 bunches equally spaced around the ring. It also includes both electron and positron beams. So a broad region of parameter space can be studied within one round of analysis.

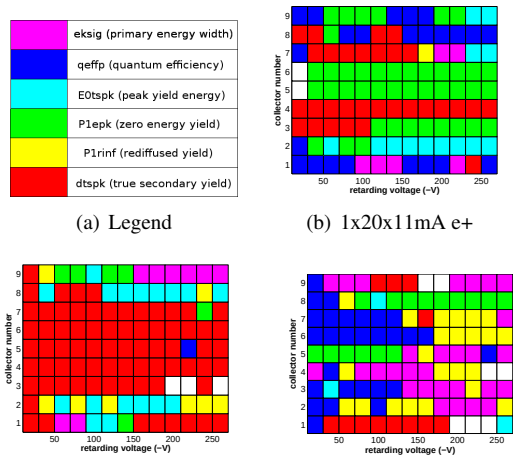
PARAMETERS

In principle this method can be used to obtain a best fit value for any number of primary and secondary electron yield parameters. In practice, due to time and disk space constraints, it is better to choose a few important parameters to fit. Table 2 lists a standard set of parameters used for this method. Note that the cloud simulations in this case were done in POSINST, so the POSINST name for each parameter is given [2]. Where two values are given for the nominal value of the parameter, the first refers to an uncoated (Aluminum) chamber, and the second to a (TiN, Carbon, or NEG) coated one. Also note that dt0pk (the total peak yield) is not an independent parameter, but rather

* Work supported by the US National Science Foundation (PHY-0734867) and Department of Energy (DE-FC02-08ER41538)
† Work supported by the US Department of Energy (DE-AC02-06CH11357)

Table 1: Set of Beam Conditions Under Study

Bunches	Spacing (ns)	Bunch Current (mA)	Species
20	14	2.8	e^+
20	14	10.75	e^+
45	14	.75	e^+
45	14	1.25	e^+
45	14	2.67	e^+
9	280	4.11	e^+
20	14	2.8	e^-
20	14	10.75	e^-
45	14	.8	e^-
45	14	1.25	e^-
9	280	3.78	e^-



(a) Legend (b) 1x20x11mA e+

(c) 1x20x11mA e- (d) 9x1x4mA e+

Figure 1: Parameter "Domains", 5.3 GeV

Table 2: Parameters Under Study

Parameter	Description	Nominal
dtspk	Peak "true secondary" yield	1.8, .8
P1rinf	"Rediffused" yield	0.2
dt0pk	**Total peak yield** (δ_{max})	**2.0, 1.0**
P1epk	Low energy elastic yield	0.5
E0tspk	Peak yield energy	310, 500
queffp	Quantum efficiency	0.1

the sum of the three secondary yield components (dtspk, P1rinf, and P1epk) at peak energy.

Parameter Domains

We want to understand where each parameter matters the most, so we can determine their values as independently as possible. One could think of this as "diagonalizing" the problem by choosing voltage scan points that depend more strongly on one parameter than any other. This is best accomplished by using data taken in a wide variety of beam conditions. Figure 1 shows the strongest parameter for a few different beam conditions, as a function of retarding voltage and collector number, color coded according to legend on the top left. In other words, the colors indicate the parameter for which a small fractional variation will have the largest effect on the simulated voltage scan. For example, the RFA signal for a 20 bunch train of electrons at high bunch current (Fig. 1(c)) depends strongly on the "true secondary" yield, while for 9 widely spaced bunches of positrons (Fig. 1(d)) the quantum efficiency and photoelectron energy distribution are the most important parameters. Note that for this analysis, primary electron yield parameters were allowed to be different for electron and positron beams, to help compensate for uncertainties in the local photon flux, as well as the fact that the energy of the incident photons can be different for the two species.

SUBTLETIES

Several subtle difficulties arise when trying to understand RFA data on a detailed, quantitative level.

Beam Pipe Hole Secondaries

Secondary electrons can be generated in the beam pipe holes below the RFA, leading to a low energy enhancement in the RFA signal. We have developed a specialized particle tracking code to quantify this effect [5], which is included in the analysis described above.

Photoelectron Model

We have found that the traditionally used low energy photoelectrons do not provide sufficient signal for electron beam data with high bunch current. A Lorentzian photoelectron energy distribution with a wide width (150 eV) has been added to POSINST to compensate for this. It is likely we will need to develop a more sophisticated model of photoelectron production to obtain complete agreement with the electron data.

Interaction with Cloud

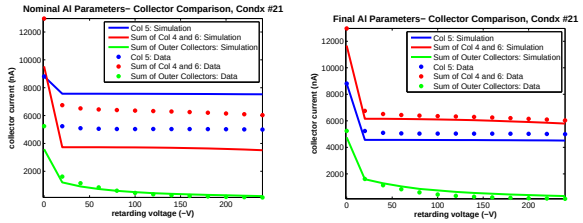
In high magnetic field regions, the presence of the RFA can have an effect on the development of the cloud. In particular, a resonance between bunch spacing and retarding voltage can occur [5]. Fully understanding this effect requires an RFA model that is integrated into the simulation code itself. This is under development.

PRELIMINARY RESULTS

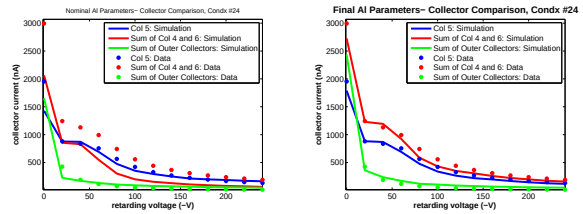
Fig. 2 shows the effect of employing the method described above for an RFA in an Aluminum drift chamber, for a few of the conditions in Table 1. These plots show the central collector in blue (collector 5 in a 9 collector RFA),

the sum of the two intermediate collectors (4 and 6) in red, and the outer collectors (1-3 and 7-9) in green. Data are shown as dots, while the simulation is plotted as a solid line. Plotting in this fashion allows for a detailed comparison of the structure of the real and predicted signal.

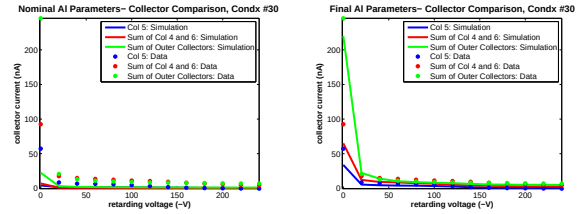
Plotted on the left are simulations done with the nominal values of each parameter (Table 2), and on the right are simulations done with the "best fit" parameters. Generally speaking this method has had some success in bringing data and simulation into agreement. In fact, for the Aluminum chamber the agreement was able to be simultaneously improved for 10 of the 11 conditions listed in Table 1.



(a) 1x20x10.75mA e+, before (b) 1x20x10.75mA e+, after



(c) 1x45x2.67mA e+, before (d) 1x45x2.67mA e+, after



(e) 9x1x4mA e-, before (f) 9x1x4mA e-, after

Figure 2: Improvement of agreement with data for 5.3 GeV, Aluminum chamber

This method was then repeated for RFA data taken in TiN, Carbon, and NEG coated chambers, with comparable results.

As stated above, the goal of this analysis is to obtain a set of simulation parameters that leads to the best agreement with data. Table 3 shows the best fit values for each chamber produced by this analysis.

There are several things to take away from this table. First, according to this analysis, TiN, Carbon and NEG coated chambers all have a very low ($< .9$) peak secondary yield, while Aluminum has a very high one. Comparing the three coatings to each other, TiN appears to come out slightly ahead. However, errors and correlations between the different parameters need to be quantified before any definitive comparisons can be made at this level. So this evaluation should be taken as preliminary.

Table 3: Best fit parameters

Parameter	Aluminum	Carbon	NEG	TiN
dtspk	2.18	0.618	0.715	.42
P1rinf	0.227	0.221	0.173	.212
dt0pk	**2.447**	**0.879**	**0.928**	**.672**
P1epk	0.416	0.26	0.452	.298
E0tspk	314	486	500	428
queffp	0.106	0.096	0.027	.093

There is some question of the ability of this method to distinguish true secondary and elastic yield, since both produce low energy secondaries. Thus one may be able to obtain similarly good agreement with data by using, for example, a somewhat lower true secondary yield and a somewhat higher elastic yield. The low value for quantum efficiency obtained for the NEG chamber is also questionable. The NEG chamber RFA is in a straight section, where the photon flux depends strongly on the elastic scattering of the photons. This is not a well known parameter, so the low quantum efficiency obtained here is probably in reality a result of an overestimation of photon flux.

CONCLUSIONS

A systematic method has been used to improve agreement between RFA data and simulation, and best fit simulation parameters have been obtained. A great deal of work remains to be done, including:

- Quantifying errors and correlations in these parameters
- Repeating the analysis for RFAs in magnetic fields, including dipoles, quadrupoles, and wigglers.
- Repeating the analysis for other beam conditions.
- Investigating the effect of other parameters.
- Comparing with other local cloud measurements, such as shielded pickups.
- Continuing development of integrated RFA models.
- Incorporating a more complete description of photoelectron emission.

If successful, the end result of this analysis will be a detailed and self-consistent description of the in situ primary and secondary emission properties of different materials.

REFERENCES

[1] R.A. Rosenberg, K.C. Harkay, Nucl. Instrum. Meth. A 453, 507 (2000)

[2] M.A. Furman and G.R. Lambertson, Proc. MBI-97, KEK Proceedings 97-17, p. 170.
M.A. Furman and M.T.F. Pivi, PRST-AB 5, 124404 (2002).

[3] F. Zimmermann and G. Rumolo, ICFA Beam Dynamics Newsletter No. 33, eds. K. Ohmi and M.A. Furman (2004).

[4] M. Palmer et. al., TH5RFP030, Proc. of PAC09.

[5] J. Calvey et. al., TUPD022, Proc. of IPAC10.