PROGRESS IN DETECTOR DESIGN AND INSTALLATION FOR MEASUREMENT OF ELECTRON CLOUD TRAPPING IN QUADRUPOLE MAGNETIC FIELDS AT CESRTA

J.A. Crittenden, S. Barrett, M.G. Billing, K.A. Jones, Y. Li, T. O'Connell, K. Olear, S. Poprocki, D.L. Rubin and J.P. Sikora
CLASSE*, Cornell University, Ithaca, NY 14853, USA

Abstract

We recently reported the first observation of electron cloud trapping in a positron storage ring (PRST-AB 18, 041001 (2015)). Following up on those 2013/4 measurements of cloud trapping in a quadrupole magnet with 7.4-T/m gradient in the 5.3-GeV positron storage ring at Cornell University, we have redesigned the shielded-stripline time-resolving electron detector with wider acceptance and improved time resolution. This summer we will install a wide-aperture quadrupole magnet at a location in the CESR ring where its field can be compensated by a nearby quadrupole. This will allow the first measurements of cloud trapping as a function of field gradient. The transverse acceptance of the electron detector has been tripled, allowing tests of model predictions indicating a dramatic cloud splitting effect which exhibits a threshold behavior as a function of bunch population. In addition, a vacuum chamber optimized for cloud buildup measurements using resonant microwave phenomena has been employed. We describe design considerations and modeling predictions for the upcoming 2016 data-taking run. This project is part of the CESR Test Accelerator program, which investigates performance limitations in low-emittance storage rings.

INTRODUCTION

The synchrotron-radiation-induced buildup of low-energy electron densities is a major concern for accelerator upgrade programs and for the design of future accelerators. Electron cloud considerations have driven the design of the SuperKEKB collider [1] and the positron damping rings for the proposed International Linear Collider (ILC) [2] and the Compact Linear Collider (CLIC).

Recently, we reported the observation of electron cloud trapping in a quadrupole magnet in the CESR positron storage ring [3]. Validation of the modeling code using measurements obtained via the Cornell Electron Storage Ring Test Accelerator project (CESRTA led to the conclusion that about 7% of the electrons in the cloud generated by a 20-bunch train of 5.3 GeV positrons with 16-ns spacing and 1.3×10^{11} population survive longer than the 2.3 μ revolution period in a quadrupole field of gradient 7.4 T/m. Extension of the model to the case of the SuperKEKB final-focus quadrupole magnets was reported at IPAC15 [4], concluding that very high electron densities are to be expected, generating betatron tune shifts more than an order of magnitude higher than the contributions from the rest of the positron ring.

Here we present the motivation for further measurements of cloud trapping and the design of the apparatus to be installed in CESR during the summer of 2016.

MOTIVATION FOR DETAILED MEASUREMENTS OF ELECTRON CLOUD TRAPPING

Numerical modeling [5] based on extensions of the EC buildup simulation code ECLOUD [6], which include the acceptance and time response of the shielded-stripline detector, achieve reasonable agreement with the measured signals, as shown in Fig. 1. However, the model also calculates a threshold behavior in the total cloud density with respect to bunch population, as shown in Fig. 2. For a minor increase in bunch population from 11.6×10^{11} to 13.2×10^{11} (7.26 to 8.26 mA/bunch), the cloud density increases by an order of magnitude. We found that this threshold behavior disappears if the rediffused component to the secondary emission yield is removed from the model. The model indicates that the reason for the apparent discrepancy between the observed signal and the cloud density is that the cloud splits transversely at the higher bunch current at the magnet pole face directly in front of the detector. A snapshot of the

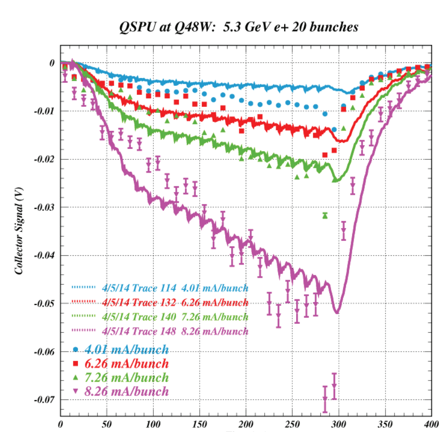

Figure 1: Comparison of modeled to measured electron detector signals for a train of 20 bunches of 5.3-GeV positrons with populations varying from 6.4×10^{11} to 13.2×10^{11} (4.01 to 8.26 mA/bunch).

* Work supported by the US National Science Foundation contracts PHY-1416318, PHY-0734867, PHY-1002467, and the U.S. Department of Energy DE-FC02-08ER41538

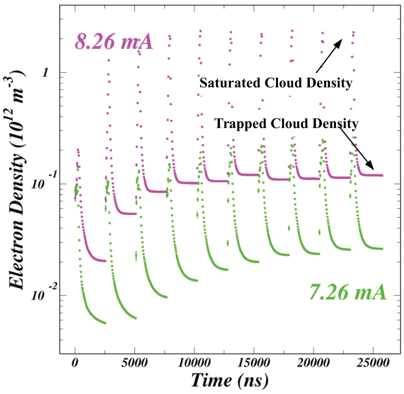

Figure 2: Results of the numerical model for the beampipe-averaged cloud density over ten revolutions for the cases of the two highest bunch populations. This density increases by an order of magnitude, while the signal modeling showed an increase of only a factor of 2.5.

transverse cloud profile at the end of the second beam revolution at the lower bunch population is shown in Fig. 3. The green lines superposed on the plot show the positions and diameter of the holes in the beampipe which allow cloud electrons to reach the detector. These lines follow the field lines of the quadrupole magnetic field, around which the cloud electrons form a tight spiral. As shown in Fig. 4, the small increase in bunch population results in a stark change in the transverse cloud profile. The reason is that the beam-kick-driven energy distribution of electrons impinging on the wall favor lower secondary emission directly on the diagonal, since those energies are higher than the maximum in the SEY dependence on incident energy. While such a splitting behavior is a well-known phenomenon in dipole magnetic fields, it has not been studied for the case of electrons trapped in quadrupole fields. We judge the non-intuitive threshold behavior of the model, and the consequences for the reliability of such electron cloud monitoring devices to

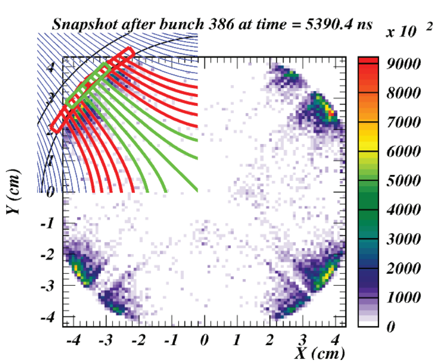

Figure 3: Modeled cloud profile at the end of the second beam revolution, i.e. following 2×183 bunch spacings for the case of 11.6×10^{11} bunch population. The insert shows the position of the vacuum chamber wall and the field lines of the quadrupole magnetic field. The green lines show the hole diameter and the positions of the rows of holes which allow cloud electrons to reach the stripline detector.

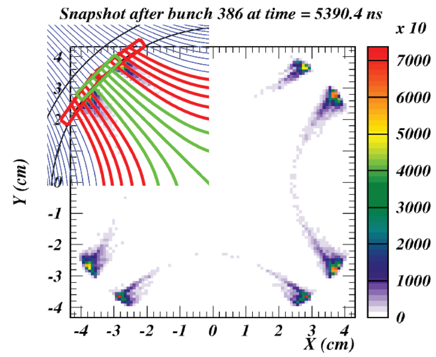

Figure 4: Effect on the cloud profile shown in Fig. 3 given by raising the bunch population from 11.6×10^{11} to 13.2×10^{11}. The red lines show the increased acceptance given by augmenting the present electron detector with two adjacent detectors.

provide information on cloud buildup in quadrupole fields, to merit further experimental investigation. The red lines in Figs. 3 and 4 show our proposed increase in detector acceptance as a means of testing the predictions of the modeling.

DESIGN FOR THE INSTRUMENTED VACUUM CHAMBER

Figure 5 shows the vacuum chamber and instrumentation to be installed in the wide-bore quadrupole magnet shown in Fig. 6. The collector and enclosure geometry have been redesigned to improve the time response of the previous stripline. The improvement removes the necessity for extensive digital filtering of the recorded signals to reduce sensitivity to a high-frequency ringing associated with the bunch passages. Aside from the three stripline enclosures, there are two ports for microwave injection and detection, providing a second measure of cloud buildup via measurements of the frequency shift of standing waves induced by the cloud density [7]. The wide-aperture quadrupole magnet will be installed in the west arc of the CESR ring this summer. At the center of the quad, the vacuum chamber will have the same 89-mm inner radius for which the 2013/4 trapping measurements were made. This new magnet will

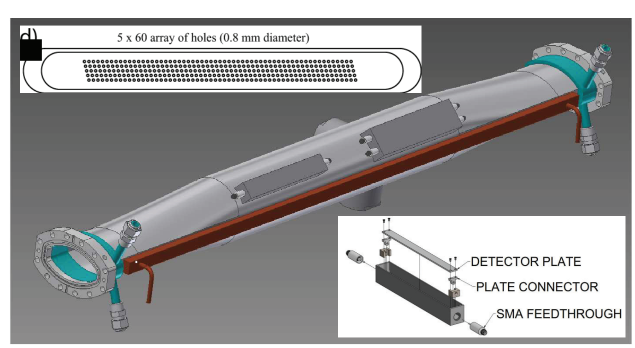

Figure 5: Schematic drawing of the new instrumented vacuum chamber design. The insets show the layout of the hole array for one of the three detectors, the enclosure for which is shown on the lower right.

ISBN 978-3-95450-147-2

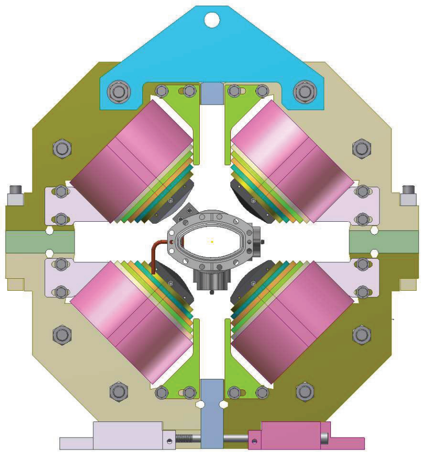

Figure 6: Schematic drawing of the vacuum chamber installed in the quadrupole magnet.

be installed adjacent to a quadrupole which presently operates at a gradient of 3.5 T/m in the 5.3 GeV lattice. Balancing the two excitations will enable us to study the trapped cloud fraction as a function of magnetic field gradient for values of the gradient reaching 3.5 T/m for the same beam fill.

MODELING PREDICTIONS

Our calculations of the modeled cloud behavior dependence on field strength led to another surprise. Figure 7 shows the predicted dependence of the trapping fraction on the field gradient. Defining the trapping fraction to be the ratio of the cloud density following the passage of the 20-bunch train to that just prior to the return of the train, as shown in Fig. 2, we reported a trapping fraction of about 7% for a field gradient of 7.4 T/m [3]. Contrary to naive expectations, the modeling shows there to be a maximum in the trapping fraction as a function of field gradient. Maximum trapping is reached at a value for the gradient of 1 T/m and is more than a factor of six (!) higher than our published

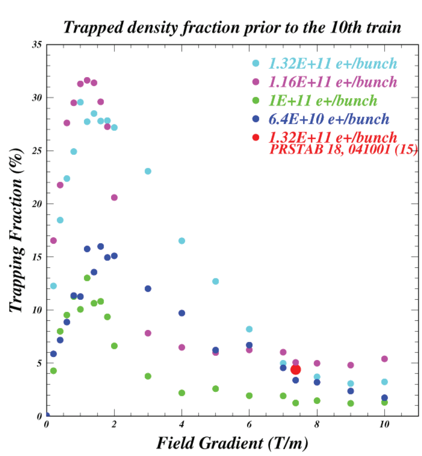

Figure 7: Dependence of the modeled cloud trapping fraction on the quadrupole magnetic field strength for bunch populations ranging from 6.4×10^{11} to 13.2×10^{11}.

result at 7.4 T/m. According to the model, the acceleration of the cloud electrons by the beam bunch passages leads to a nonlinear increase in average secondary emission yield at the wall, primarily because the incident angles are more grazing, and a much greater fraction of the resulting cloud kinematic distribution can be trapped.

SUMMARY

The CesrTA project will continue its study of electron cloud trapping in a quadrupole magnetic field, adding the ability to vary the magnetic field strength up to 3.5 T/m. The acceptance of the shielded stripline electron detector will be tripled in order to verify a cloud splitting phenomenon predicted by numerical modeling of cloud buildup and detector response. The new design of the vacuum chamber instrumentation will include optimal placement of microwave detectors and standing-wave terminations for additional measurements of cloud buildup to cross-calibrate with those of the shielded striplines. The new apparatus will serve to test a remarkably strong dependence on bunch population and field strength predicted by numerical modeling.

REFERENCES

[1] Y. Suetsugu *et al.*, “Design and Construction of the SuperKEKB Vacuum System,” *J. Vac. Sci. Technol. A* **30**, 031602 (May 2012).

[2] J. A. Crittenden *et al.*, “Investigation into Electron Cloud Effects in the International Linear Collider Positron Damping Ring,” *Phys. Rev. ST Accel. Beams* **17**, 031002 (Mar. 2014).

[3] M. G. Billing *et al.*, “Measurement of Electron Trapping in the Cornell Electron Storage Ring,” *Phys. Rev. ST Accel. Beams* **18**, 041001 (Apr. 2015).

[4] J. A. Crittenden, “Initial Modeling of Electron Cloud Buildup in the Final-Focus Quadrupole Magnets of the SuperKEKB Positron Ring,” in *IPAC2015: Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA* (2015), Paper TUPTY079.

[5] J. A. Crittenden *et al.*, “Numerical Modeling for CESRTA Measurements of Electron Cloud Buildup in a Quadrupole Magnet,” in *IPAC2014: Proceedings of the 5th International Particle Accelerator Conference, Dresden, Germany*, C. Petit-Jean-Genaz *et al.*, Eds., JACoW, Geneva, Switzerland (2014), p. 1632–1634.

[6] F. Zimmermann, G. Rumolo & K. Ohmi, “Electron Cloud Build Up in Machines with Short Bunches,” in *ICFA Beam Dynamics Newsletter*, K. Ohmi & M. Furman, Eds., International Committee on Future Accelerators, No. 33, p. 14–24 (Apr. 2004).

[7] J. P. Sikora, Y. Li & S. De Santis, “Microwave Modeling for Electron Cloud Density Measurements at CESRTA,” in *IPAC2015: Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA* (2015), Paper MOPWI031.