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A NEW CHICANE EXPERIMENT IN PEP-II TO TEST MITIGATIONS OF THE ELECTRON CLOUD EFFECT FOR LINEAR COLLIDERS*

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Abstract

Beam instability caused by the electron cloud has been observed in positron and proton storage rings, and it is expected to be a limiting factor in the performance of future colliders [1-3]. The effect is expected to be particularly severe in magnetic field regions. To test possible mitigation methods in magnetic fields, we have installed a new 4-dipole chicane experiment in the PEP-II Low Energy Ring (LER) at SLAC with both bare and TiN-coated aluminum chambers. In particular, we have observed a large variation of the electron flux at the chamber wall as a function of the chicane dipole field. We infer this is a new high order resonance effect where the energy gained by the electrons in the positron beam depends on the phase of the electron cyclotron motion with respect to the bunch crossing, leading to a modulation of the secondary electron production. Presumably the cloud density is modulated as well and this resonance effect could be used to reduce its magnitude in future colliders. We present the experimental results obtained during January 2008 until the April final shut-down of the PEP-II machine.

INTRODUCTION

An electron cloud may be initiated by photoelectrons or ionization of residual gas and increase by the surface secondary emission process. Possible remedies for the electron cloud include thin-film coatings, surface conditioning, photon antechamber, clearing electrodes and chamber with grooves or slots [4-12]. To test the effect in magnetic field, we have installed a new chicane with instrumented chambers in aluminum and TiN coating, in the operating collider PEP-II LER. Other electron cloud ILC tests in PEP-II are described in [13].

CHICANE INSTALLATION IN PEP-II

We have installed a 3.4 m long “test” aluminum chamber in Interaction Region 12. The chamber has been partially coated with TiN, see Figure 2.
The 4-magnet chicane was installed in this section. Three of the four magnets were covering the test chamber and the fourth magnet was covering a spool chamber. The test chamber has been instrumented with electron detectors inside each magnet location. The field of the chicane dipoles could be adjusted in the range 0-1.46 kG, the top limit corresponding to the nominal magnetic field strength of the ILC DR arc dipoles. The electron detectors (or analyzers) shown in Figure 3 were placed in an aluminum box externally welded to the top of the vacuum chamber and located in the dipoles. The electron detectors each consisted of three grids and 17 stripe collectors. This type of instrument is a retarding field analyzer (RFA).

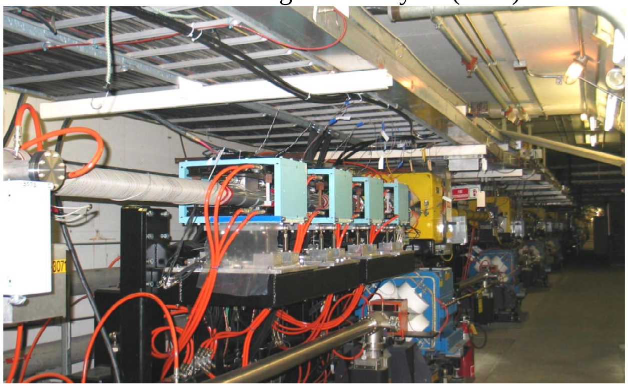

Figure 1. Detail of the newly installed 4-dipole chicane in the PEP-II LER in IR12 (upper beam line). The clearing solenoid can also be seen upstream of the first magnet (left side of the picture).

Table 1. PEP-II LER beam and chicane parameters.

PEP-II ring circumference – m	2199
PEP-II positron LER current total – mA	2500
Bunch spacing – ns	4.2
Chicane magnet length – m	0.4357
Chicane magnetic field – kG	0 to 1.46
Vacuum chamber diameter – mm	89
Vacuum chamber surface materials	Al and TiN

The stripe collectors, distributed in the horizontal plane and each extending 76 mm along the beam direction, allowed for measuring the spatial horizontal electron distribution. Holes (2 mm diameter) in the vacuum chamber allowed the electrons to leave the chamber vertically and enter the detector area.

By design, the chicane generated a 3.5 mm maximum beam orbit horizontal offset. A solenoid was also arranged along 2 m of the test chamber, Figure 1, upstream and between the magnets. The impact on PEP-II machine operations was small; turning on the 2 m long solenoid generated ~4% increase in the collider luminosity. Furthermore, turning on the chicane magnets generated 1-2% luminosity increase and the positron beam orbit changed along the ring by an acceptable 90 um average rms.

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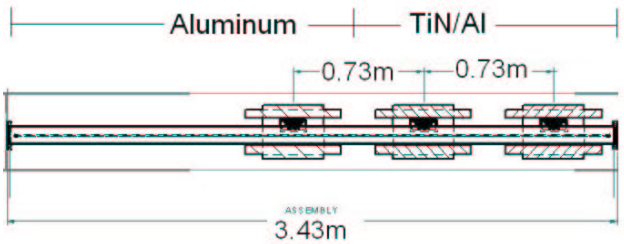

Figure 2. Layout of the test aluminum vacuum chamber, coated with TiN at the 2nd and 3rd magnets location.

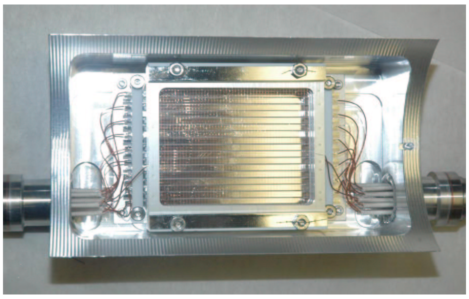

Figure 3. Electron detectors were placed in an aluminum box externally welded to the top of the vacuum chamber. Each consisted of 17 stripe collectors and 3 grids located between the collectors and the beam. The collectors are 76 mm long, 2.54 mm wide and separated by 0.5 mm. Each collector was biased with a positive potential +45 V to attract secondary electrons back to the collector.

NEW RESONANCE EFFECT OF ELECTRONS IN A DIPOLE FIELD AND EXPERIMENTAL RESULTS

The experimental plan consisted in i) testing the efficiency of TiN coating with respect to aluminum surface ii) measuring the cloud current as a function of beam current iii) measuring the electron energy spectrum iv) verifying the existence of a new resonance behavior of electrons in a dipole field as predicted by previous simulation results [14].

At first, we measured the electron collector signal in both the aluminum and the TiN sections with the chicane magnets off. The electron current signal in the TiN section was a factor ~30 lower than in the aluminum section.

Then, we turned the chicane on and measured the electron collector current as a function of the positron beam current. The results are shown in Figure 4 for the aluminum section and Figure 5 for the TiN section for a fixed dipole field of ~850 G. The plots are in the same vertical units. The orders of magnitude larger electron cloud current measured in the aluminum with respect to the TiN section supports previous observation of a higher SEY~2 of aluminum [15]. Two electron cloud stripes developed at high beam current, characteristics of the electron spatial distribution in the dipole field [16, 17]. In dipoles, the electron cloud density develops mostly at a horizontal distance from the beam center where the electron wall impact energy gain corresponds to the peak of the surface secondary electron yield (SEY).

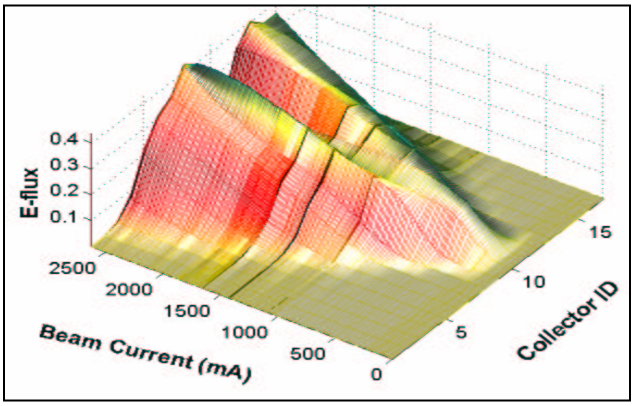

Figure 4. Aluminum section. Measured electron cloud signal as function of beam current and chicane dipole field ~850 G. Two stripes at high beam current.

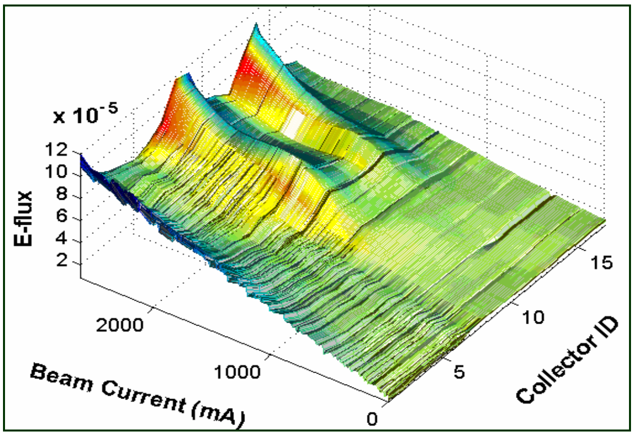

Figure 5. TiN section. Measured electron cloud collectors signal as function of beam current and chicane dipole field ~850 G. Signal suppressed by TiN coating compared to the uncoated aluminum section.

Furthermore, we measured the electron collector current as a function of the chicane dipole field, Figure 6. The electron flux shows resonance peaks and valleys as the dipole field increases similar to that predicted by recent simulation [14]. In a magnetic field, the electrons gain the maximum energy, if the electrons cyclotron period is an integer multiple of the spacing between two bunches. The cyclotron gyration period τ_c is only function of the magnetic field $\tau_c = 2\pi m_e \gamma / eB$, thus the electron stays in resonance until detuned by the relativistic mass increase or space charge. If we define [14]

$$n = \frac{t_b}{\tau_c} = \frac{t_b eB}{2\pi m_e \gamma} \qquad (1)$$

where B is the magnetic field induction, t_b the spacing in time between bunches, m_e the electron mass, e the electron charge and γ is the electron relativistic energy factor, thus n represents the number of gyro-periods executed by an electron in between two consecutive bunches.

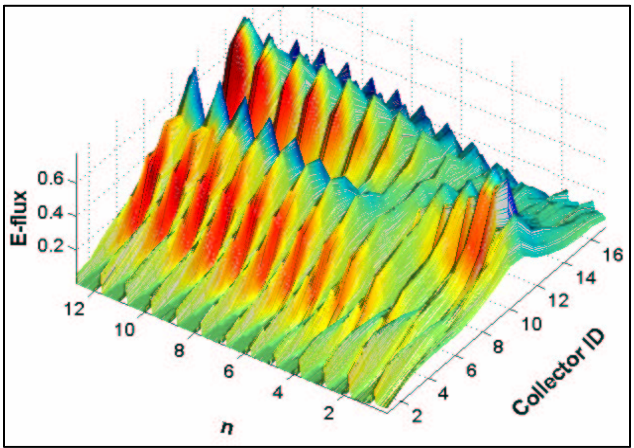

Figure 6. Measured electron cloud collectors current as a function of the chicane dipole field in the aluminum section. Resonance peaks are visible. The parameter n varies linearly with the magnetic field; $0 < n < 13$ corresponds to a magnetic field variation between 0 and ~1.1 kG. Vertical arbitrary raw data scale. Beam current 2500 mA.

The cyclotron resonance causes a modulation of the electron energy gain with a maximum energy gain at integer values of *n*. In turn, a variation in the energy gain results in a variation of the secondary electrons generated as determined by the SEY, and presumably in the final electron cloud density. Thus, according to this model, the measured electron cloud current should show peaks and valleys as the magnetic field varies.

The measured peaks in Figure 6 are separated exactly by integers of *n*. However, the peaks are not at the predicted locations. Although, simulations predicted several features of the measured data, some experimental results still need to be understood. For example, the experimental results obtained for the TiN and the aluminum sections are qualitatively different. The electron flux collected in the TiN section presented maxima at $n \cong$ integers+0.85 and minima at $n \cong$ integers+0.35 close to the expected simulation values. Conversely, the aluminum section presented maxima and minima shifted by half-integer of *n* with respect to the TiN section. The different resonant behavior might be due to differences in the surface SEY or differences in the electron cloud density and thus in space charge forces.

An intensive simulation campaign is started at SLAC and LBNL with state-of-the-art simulation codes to study the effect and benchmark the experimental results. The experimental setup will be transferred to Cornell University and studies will continue under the Cesr Test Accelerator (CesrTA) program. Chambers with grooves and non-evaporable getter coating have been built but not completed due to restrictions in the US ILC funding in 2008. The groove chamber will be installed and tested in CesrTA.

CONCLUSIONS

From the electron cloud chicane tests, we report two important results in dipoles i) the TiN coating reduces the cloud density by several orders of magnitude with respect to a bare aluminum surface and ii) we observed a new resonance phenomenon that results in the modulation of the electron wall flux, and hence presumably of the electron cloud density. As a benefit for the future colliders as the ILC DR, we should be able to reduce the electron cloud density by a factor ~3 by tuning the arc dipole field by few tens of G. Furthermore, we measured the electron energy spectrum and the horizontal electron cloud distribution at the wall. A simulation effort is started to study the novel resonance effect and benchmark against experimental observations.

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