BEAM INDUCED DETECTOR BACKGROUNDS FOR CESR AND CLEO

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ABSTRACT

Detector backgrounds induced by the beam are studied at CESR and CLEO-II. Data are presented for typical running conditions, the effect of changes in shielding, and the effect of changes in vacuum pumping. The data are compared to the predictions of simulations of this background based on synchrotron radiation and beam gas interactions. These simulations are then used to design shielding for upgrades to the CESR-CLEO interaction region.

Beam induced detector backgrounds are a major consideration in the design of interaction regions at e^+e^- accelerators. The CLEO-II detector at the Cornell Electron Storage Ring (CESR) is a nearly ideal case to study the undesired effect of the beams on a precision detector due to CESR's high beam current and CLEO-II's 3.5cm radius Be beam pipe. Beam particles can be "lost" by scattering off of the residual gas in the storage ring. Such lost particles can impact near the CLEO-II interaction point and induce unwanted noise and deposit radiation on the sensitive and delicate detector elements. Another source of noise and radiation is synchrotron radiation caused by the beam being accelerated transversely in the magnetic field of bend and focusing magnets. These synchrotron x-rays are copiously produced by CESR's high current beams.

A simulation of beam induced background in the CESR-CLEO-II interaction region has been written. It is described in detail in,[1] and here we briefly mention its main features. Beam particles can scatter off the residual gas in the ring by Coulomb scattering or Bremsstrahlung. The scattered beam particle and the photon from Bremsstrahlung are tracked through the CESR lattice until they strike the wall of the vacuum chamber. Those that strike near CLEO-II are then input to the standard CLEO-II detector simulation. Synchrotron x-rays are generated in the magnetic elements near CLEO-II. Their spectrum depends on the parameters of the beam and the strength of the bending magnetic field. The processes of x-ray interactions with matter, photo-absorption, fluorescence, Compton scattering and Rayleigh scattering, are considered to generate a spectrum of photons incident on the sensitive parts of the detector.

The CLEO-II detector has been described in detail elsewhere,[2] and here I briefly mention those parts used in the studies described below. Closest to the beam pipe is a 6 layer tube chamber called the Precision Tracking Layers (PTL). The current drawn by the first layer of the PTL, at a radius of 4.7cm, is sensitive to both synchrotron radiation and lost particles and is used as the primary measure of background conditions. The lowest level trigger rate, called the L0 rate, is dominantly sensitive to lost particles as the trigger requires firing of Time-of-Flight counters which are not sensitive to x-rays from synchrotron radiation.

The comparison of the PTL layer 1 current draw and the L0 rate at different beam currents can give an indication of the relative contributions of synchrotron radiation and lost particles to beam induced backgrounds in CLEO-II. This comparison makes use of the fact that the amount of synchrotron radiation is directly proportional to the beam current while the amount of lost particles depends on the beam current times the pressure of residual gas in the ring. The residual gas pressure has a component that is constant and a component that depends linearly on the beam current due to synchrotron radiation causing desorption from the chamber walls. Thus the amount of lost particles depends on two factors one of which is linear with the beam current and the other which goes at the square of the beam current. Symbolically I can write

$$\begin{aligned} \mathrm{L0} &= \alpha \mathrm{I}^2 + \beta \mathrm{I} && (1) \\ \mathrm{PTL1} &= \mathrm{T}(\alpha \mathrm{I}^2 + (\beta + \Delta\beta)\mathrm{I}) , && (2) \end{aligned}$$

where L0 is the L0 rate, I is the beam current, PTL1 is the PTL layer 1 current, and α, β, $\Delta\beta$, and T are constants obtained from fitting the measured data for L0 and PTL1 versus the beam current to second order polynomials. Interpret $\alpha\mathrm{I} + \beta$ as proportional to the pressure of residual gas in the ring, and thus $\alpha\mathrm{I}^2 + \beta\mathrm{I}$ is the contribution of lost particles to detector background. Then $(\Delta\beta)\mathrm{I}$ is the contribution of synchrotron radiation background which does not contribute to the L0 rate. The factor T is simply the constant of proportionality between lost particle background contribution to the L0 rate and PTL layer 1 current draw and can be obtained from the data by dividing the fitted coefficients on the I^2 terms in the PTL layer 1 current and the L0 rate data. The relative contribution of synchrotron radiation to the total background at a given beam current is then given by

$$\frac{\Delta\beta}{\alpha\mathrm{I} + \beta + \Delta\beta} \, . \tag{3}$$

The validity of equation 3 depends on the two assumptions that synchrotron radiation has a negligible impact on the L0 rate and that the relation between lost particle contribution to the L0 rate and PTL layer 1 current is a simple constant.

Data was taken in September of 1992 for the PTL layer 1 current and the L0 rate as a function of beam current for both a single positron beam and a single electron beam. Table 1 gives the results for the fits to this data. Note that the T parameter is consistent for the single electron and positron beam data confirming one of the assumptions on the validity of this approach. Note that the α parameter is much larger for the positron beam than the electron beam, while the two β parameters are similar. This would imply that with no beam in the ring the pressure of residual gas on the electron and positron side should be similar, which is observed, but as beam is loaded into the ring the positron side should show a higher pressure rise than the electron side. This is confirmed by measuring the pressure with single beams of about 70mAmps. The

Table 1. Results of fits to single electron and positron beam data. See the text for the definition of the parameters.

Parameter	Electron Beam	Positron Beam
T (μAmps/kHz)	0.233 ± 0.050	0.290 ± 0.017
α (kHz/mAmp^2 $\times 10^{-4}$)	1.72 ± 0.05	4.67 ± 0.05
β (kHz/mAmp $\times 10^{-4}$)	178 ± 27	151 ± 32
$\Delta\beta$ (kHz/mAmp $\times 10^{-4}$)	125 ± 77	306 ± 34

Table 2. Comparison between data and the prediction of the simulation for the measures of beam induced backgrounds. All are made with a single beam current of 70mAmps.

	PTL Layer 1 Current (μAmps)	L0 Rate (kHz)
Positron Lost Particle Simulation	0.45	1.52
Positron Synchrotron Simulation	0.72	0.00
Positron Beam Simulation	1.17	1.52
Positron Beam Data	1.36	3.35
Electron Lost Particle Simulation	0.30	1.01
Electron Synchrotron Simulation	0.13	0.00
Electron Beam Simulation	0.43	1.01
Electron Beam Data	0.55	2.09

positron side shows a pressure 1.5 times the electron side which is consistent with the ratio of $\alpha I + \beta$ for the two beams which gives 1.6. Also note that the contribution of synchrotron radiation to the background (the $\Delta\beta$ term) is much larger for the positron beam than it is for the electron beam. This is discussed further below.

I can also compare the two measures of background with the absolute prediction of the simulations of the background processes. The amount of lost particle background depends on the distribution of residual gas, assumed to be N_2, pressure around the CESR ring and measurements of the pressure at various points around the ring are combined with the known pumping speeds of pumps and the conductance of the vacuum chamber and pumping ports to give a pressure distribution that is an input to the lost particle simulation. Table 2 compares the results of the prediction of the simulation and the data for the background measures. Figures 1 and 2 display the azimuthal distribution of the current in PTL layer 1 for the electron beam and the positron beam respectively comparing the prediction of the simulation with the data. The simulation is a very good description the features visible in the data. The peak on the outside ring is due to lost particles that are over bent by the nearest bend and then over focused by the powerful horizontally focusing quadrupole 2.5 meters upstream of the interaction

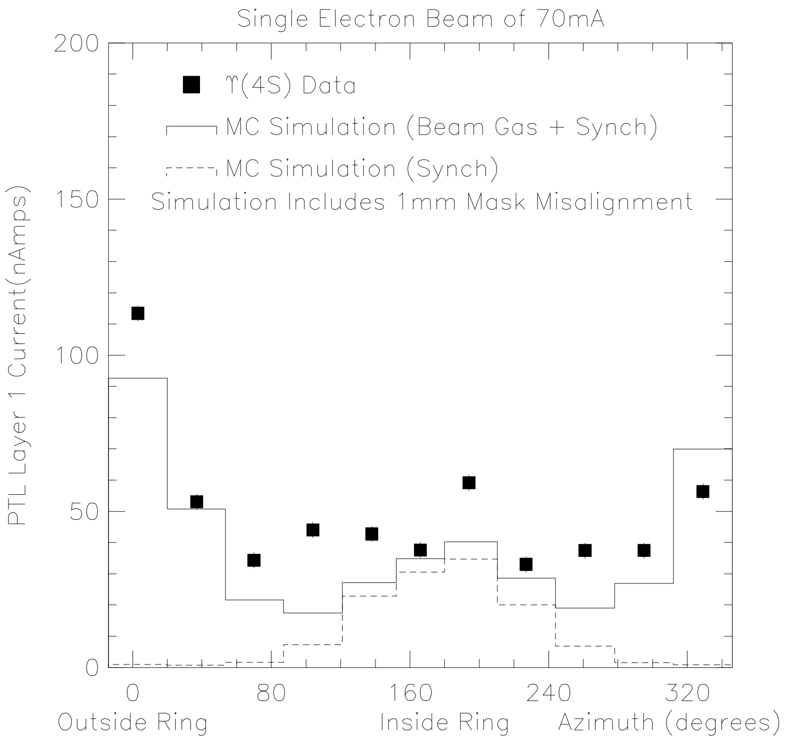

Fig. 1. The azimuthal distribution of the current in the first layer of the PTL induced by the electron beam.

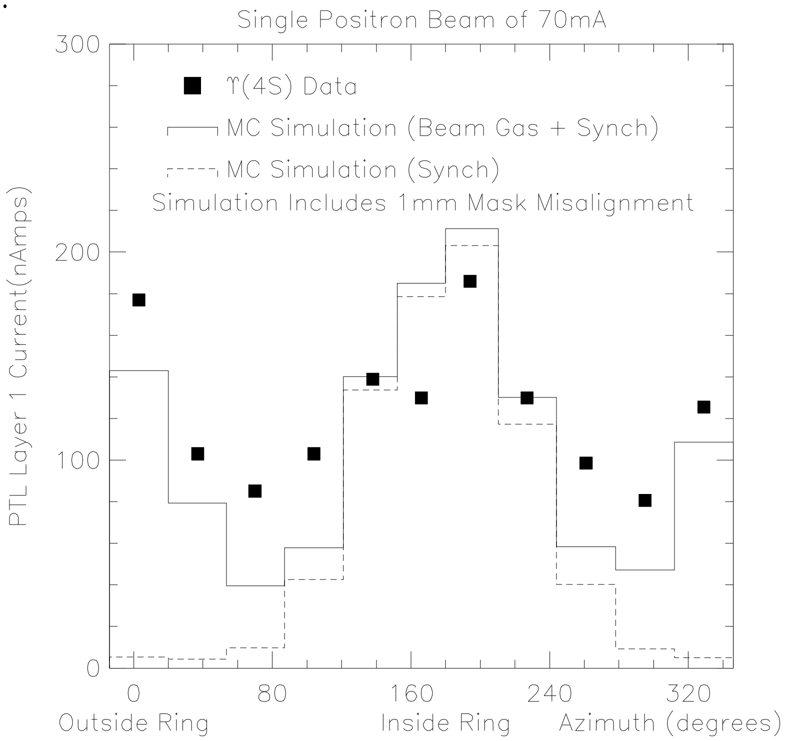

Fig. 2. The azimuthal distribution of the current in the first layer of the PTL induced by the positron beam.

point. The peak on the inside of the ring, clearly visible for the positron beam, is due to synchrotron radiation back-scattering off of the mask 35cm from the interaction point on the outside of the ring. Quantitatively the simulation predicts the current draw and trigger rate to within a factor of two. This is good performance when all the sources of error that may effect the simulation are taken into account. The pressure profile used in the lost particle simulation is based on only a few reliable measures of the residual pressure and a simplistic model of pumping and conductances. Much of the synchrotron radiation induced background is absorbed in the 25μm coating of silver on the inner wall of the CLEO-II beam pipe. The non-uniformity of the coating thickness is not included in the simulation and this introduces a factor of 2 error in the amount of background incident on the detector. These and other sources of error lead us to conclude that the simulation is only accurate to within a factor of 2 on its prediction of absolute backgrounds.

The simulation predicts that synchrotron radiation should contribute 62% of the background in the first layer of the PTL for the positron beam and 30% for the electron beam for beam currents of 70mAmps. The fits to the backgrounds as a function of beam current indicate that these numbers should be 39% and 33% respectively using equation 3 and the fitted parameters in table 1. This agreement is good considering the uncertainties in the absolute rates for the simulation discussed above. Our studies have shown that the difference between the backgrounds induced by the electron and positron beam is caused not only by the difference in the pressure on the two sides of the ring, but also by synchrotron radiation from the bending magnet nearest to CLEO-II. Studies of closed orbit bumps reveal that the positron beam's background can be reduced by displacing the beam towards the outside of the ring in this bend. The two unusual effects, no synchrotron back-scattering peak visible in the electron data and the asymmetry of the background from the positron and electron beam, are caused by a 1mm misalignment of the IR masks that shield CLEO-II from synchrotron radiation. The masks are misaligned in such a way as to increase their shielding power for the electron beam, and decrease it versus the positron beam. The effect of this misalignment on the background induced by the positron beam would be minimized by displacing the beam to the outside of the ring as has been observed.

The simulation has done quite well in predicting the effect of changes to the CLEO-II interaction region on backgrounds. In June of 1992 the masks 2.0 meters from the interaction point were redesigned to reduce their slopes, thereby reducing the amount of energy deposited on them due to higher order mode (HOM) heating, and withdrawn to give more aperture during injection. The simulation predicted that such a redesign would have no effect on the synchrotron radiation background and slightly increase the amount of lost particle background. The simulation predicted a rise of $15\pm15\%$ while a rise of 12% was observed. Note that the errors on the prediction of changes in background are much smaller than the prediction of absolute backgrounds as many of the systematic effects cancel in the ratio. In November of 1992 the vacuum pumping in the bend nearest to CLEO-II was improved by the installation of titanium sublimation pumps. These pumps were expected to reduce the residual gas pressure in this region by a factor of 5. The simulation predicted that a large fraction of the lost particle background is generated by scatters off of gas in this bend and it was expected that this improved pumping would lower the chamber current draw by $25\pm15\%$ and a 25% reduction was observed. Both of these results give us confidence in the ability of the simulation to predict the backgrounds for other interaction regions.

The techniques used to study detector background for CLEO-II have been used as design tools for a redesigned CLEO II interaction region (IR) with a 2.0cm radius, actively cooled beryllium beam pipe and three layer silicon strip vertex detector surrounding it. This redesign is described in detail elsewhere[3] and here only a few key points are discussed.

Masks of high-Z materials are used to shield the detector from lost particle backgrounds. In the redesign tungsten will be the mask material. Synchrotron radiation background is absorbed with tips on the tungsten masks and is further reduced by a thin layer of gold coated on the inside of the beryllium beam pipe. Further reductions in the amount of synchrotron radiation induced background are obtained by carving small steps ($\approx$1mm) in the surface of the tungsten mask as it slopes up from the vacuum chamber radius of 4.5cm to the mask tip radius of 1.2cm. These two features, the gold coating and the steps, each give about a factor of 100 reduction in the amount of synchrotron radiation induced background in the detector.

The overall performance of the redesigned CLEO II IR is well within the requirements for good operation of the silicon detector. Occupancy is predicted to be below $0.1\%/\mu$sec on the inner layer of detector and radiation dosages on the sensitive integrated circuit readout chips of the detector are at acceptable levels for long operation. All of this takes into account the expected total beam current of 600mAmps that CESR will achieve during the projected running time of this redesigned IR.

In summary a simulation of beam induced detector background has been developed that gives good results when compared to the data taken at CLEO-II at CESR. This simulation has quantitatively predicted the effect of mask misalignment, mask changes, and vacuum improvements. This simulation has been used as a design tool for an upgraded CLEO-II IR.

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