DESCRIPTION OF A HIGH RATE LUMINOSITY MONITOR INSTALLED AT CESR

G. P. Jackson and S. W. Herb*
Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, N.Y. 14853

Abstract

In response to a need for a fast, direct measure of luminosity for the purpose of machine optimization, a high rate luminosity monitor has been constructed for CESR. The interaction regions at CESR employ a standard minibeta lattice in which the inner quadrupoles are vertically focussing. Bhabha scattered particles are horizontally defocussed upon traversing these quadrupoles. A beam pipe constricted in the horizontal plane was constructed to detect these high event rate particles. This paper is a description of the luminosity, background, and accidental rates observed with various detector schemes. These results are compared with calculations. Stability and beam steering sensitivies are also explored.

Motivation

The Cornell Electron Storage Ring (CESR) is an e+e- accelerator used primarily for the study of high energy particle physics. The primary responsibility of the accelerator physicists at Cornell is maximizing the luminosity delivered to experiments.

In order to optimize a given variable, one must be able to measure it on a reasonable time scale. In the past CESR operators have not tuned the machine using luminosity monitors (LM) for feedback due to low rates. For example, the CLEO detector LM runs at scaler rates of 13 Hz/10^{31} cm^{-2} sec^{-1}, which means that at typical luminosities of 2-3 x 10^{31} cm^{-2} sec^{-1} one minute is required for a statistically significant response to a given operator action. Therefore operators use other measureable quantities (vertical beam height, σ-π tune split) for machine performance feedback, even though the correlations between them and the luminosity are not always simple.

We have designed and tested a high rate luminosity monitor for the CLEO detector. It has a counting rate roughly 20 times the old LM, which means that 3 to 4 seconds of integration yields a number statistically significant at the 3% level.

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Geometry

Figure 1 is a schematic representation of half of the CLEO detector interaction region. A minibeta magnet lattice is currently used in CESR, requiring that the first quadrupole (Q1) be horizontally defocussing. To take advantage of this increased horizontal trajectory dispersion, short sections of beam pipe narrowed to +-3 cm horizontal aperture (Figure 2) were installed just outside of these quadrupoles so that detectors could be moved in to detect very low angle (9 mrad) Bhabha scattered electrons and positrons. These narrow sections also serve to mask synchrotron radiation from the bending magnets closest to the interaction region.

The quadrupoles are normally rotated at about a 3^{o} angle as part of the compensation for the coupling introduced by the 1 Tesla field of the CLEO solenoid. This is a small effect for the LM rates and in this paper we assume that the solenoid is off and the quadrupoles are not rotated. All calculations were done using a Q1 focussing strength of -0.648 m^{-2}, an effective length of 0.95m, and 5.3 GeV beam energy.

Rates

For a point beam with no divergence the differential cross section for Bhabha scattering in terms of machine variables at the interaction point is

$$\frac{d\sigma}{dx'\,dy'} = \frac{4\,\alpha^2\,(\hbar c)^2}{E_o^2}\,\frac{1}{(x'^2 + y'^2)^2} \tag{1}$$

We take the active region of the detector to be as shown in Figure 2. Projecting the particle trajectories through Q1 and integrating those subsequent positions over the detector surface area, one finds that the counting rate is given by the integral in Equation 2. k is the strength of Q1 and δ is the drift space between Q1 and the interaction point.

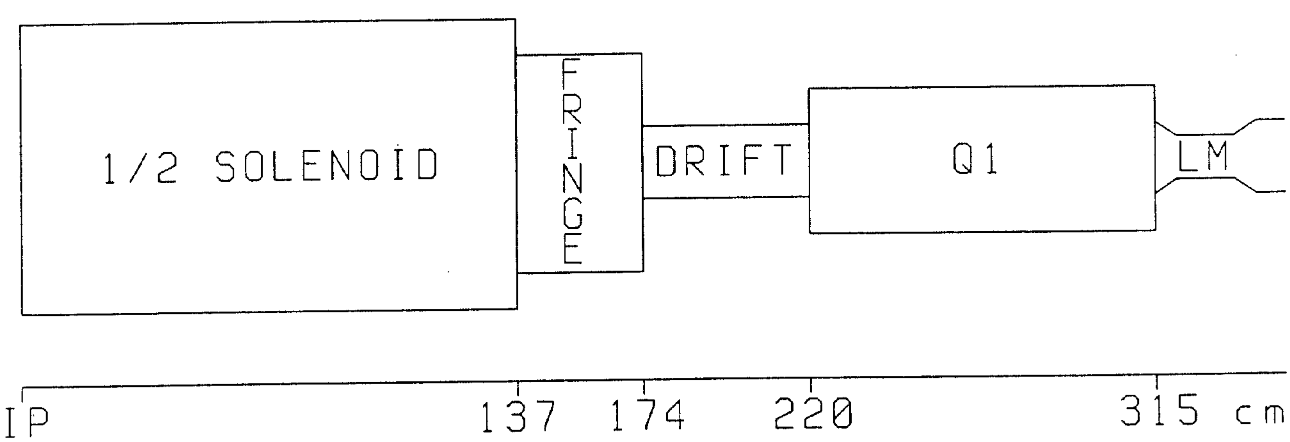

Figure 1: Top view of the interaction region

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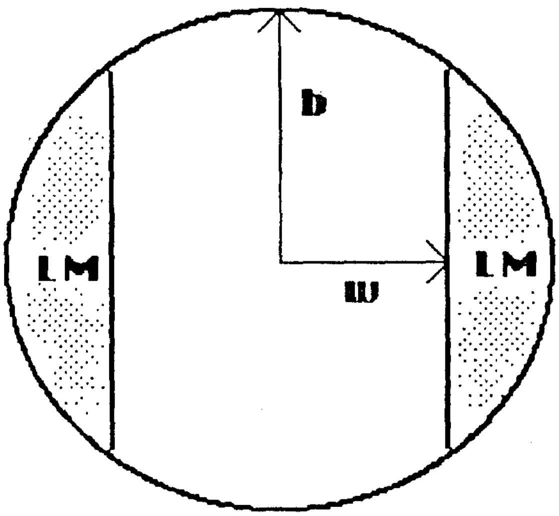

Figure 2: This sketch is a beam's eye view of the constriction installed at the CLEO detector. The pipe radius is 5.7 cm.

$$R = \frac{8\alpha^2(\hbar c)^2\, L}{p\, q\, E_o^2} \int_w^b dx \left\{ \frac{p^4 q^2 x\, [b^2-x^2]^{1/2}}{D} + \frac{(p^3q^3x^2+p^5q\,[b^2-x^2])\ \mathrm{TAN}^{-1}(p\,[b^2-x^2]^{1/2}/q)}{D} \right\} \qquad (2)$$

where

$$D = q^2x^5 + p^2x^3[b^2-x^2]$$

$$p = \mathrm{SINH}(\sqrt{k}l)/\sqrt{k} + \delta\ \mathrm{COSH}(\sqrt{k}l)$$

$$q = \mathrm{SIN}(\sqrt{k}l)/\sqrt{k} + \delta\ \mathrm{COS}(\sqrt{k}l)$$

Equation 2 was integrated numerically for CESR conditions to produce the curve in Figure 3. The +-3 cm aperture used for the beam pipe is the minimum which does not reduce the horizontal beam aperture in CESR.

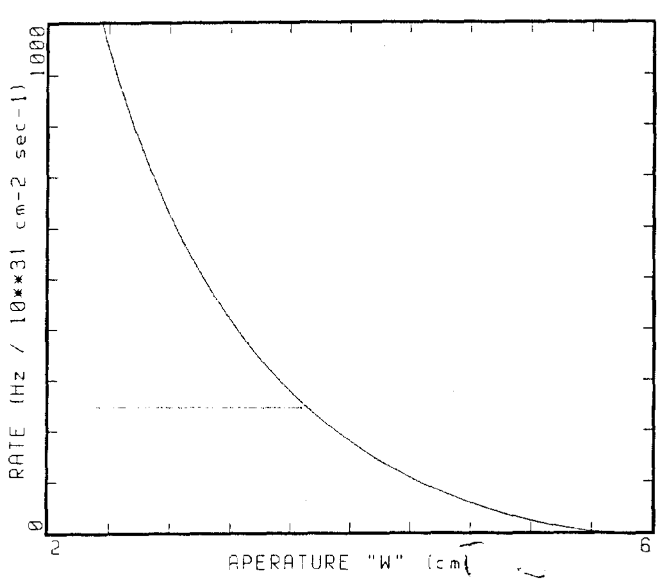

Figure 3: Luminosity counting rate (two coincidence arms) vs detector depth into the beam pipe. The lines show the present detector configuration.

Four slabs of 1 cm thick scintillator, instrumented with phototubes, were placed in the constrictions to build two luminosity and two accidentals coincidence arms. The measured counting rates were consistent with Equation 2.

Singles, Accidentals, and Radiation

Our primary concern for this luminosity monitor was that high background rates close to the beam might result in unacceptable levels of accidental coincidences. Our initial measurements used the four scintillation counters, each preceded by one radiation length of lead. A threshold corresponding to about four times minimum ionizing pulse height gave good efficiency for the luminosity coincidences. The singles rates per counter were about 15 kHz at peak beam current with colliding beams and 4-5 kHz at lower currents typical of the end of a high energy physics run. CESR was operating with 3 bunches per beam, giving bunch spacings of about 850 nsec. The corresponding measured accidental/real coincidence ratios were roughly 0.30 and 0.02.

A complete set of electromagnetic calorimeters has not yet been installed; however, we have replaced one of the counters with a lead-scintillator calorimeter. With this signal plateaued for the 5 GeV Bhabha scatters, the singles rate is about a factor of three lower than for the individual counters. We estimate that by using calorimeters and fiducial counters with up-down segmentation we should achieve accidental/real ratios of 5% or less for normal operating conditions.

In order to evaluate the type of detectors which can survive in a environment so close to the beams, we have also measured the radiation level in the beam pipe constriction by inserting thermoluminescent devices (TLD's) for several days. A typical dose was about 50 Rad/day ; this is almost certainly dominated by losses during injection into CESR.

Steering Sensitivity

A simulation was written to estimate the effect of beam position and angle variations at the interaction point. The program predicts complete insensitivity to vertical beam perturbations and 10% variations in the total (two arm) luminosity rate for large horizontal steering changes.

Measurements with CESR verified these predictions. No vertical sensitivity was measured, and horizontal steering effects (at the 10% level) occurred near the aperture (lifetime) limit of the machine.

Conclusions

A high rate luminosity monitor has been designed and tested in CESR. Its performance matches our calculations. Although not suited to absolute luminosity measurements (due to low level steering sensitivities and accidental rates), it should become a useful tool for machine optimization.

Future Plans

The beam pipe constrictions were placed in the machine as a test of the feasibility of such a detector. Due to its success and the constraints involved in the installation of a microbeta lattice in early 1986, such detectors will be the only dedicated luminosity monitors in the new machine.