DESIGN AND OPERATION OF A RADIATIVE BHABHA LUMINOSITY MONITOR FOR CESR-c*

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Abstract

The CLEO-c experiment at the Cornell Electron Storage Ring (CESR) is presently embarking on a multi-year exploration of charm and QCD physics in the 3–5 GeV center-of-mass energy range. In order to facilitate rapid optimization of machine parameters over this energy range, a luminosity monitor based on the measurement of radiative-Bhabha photons coming from the CLEO-c interaction point (IP) has been designed and installed in the CESR ring. Key design criteria of the device include: better than 1% statistical measurements of the luminosity with a 1 Hz update rate over the full range of CESR-c operating conditions; bunch-by-bunch measurement capability; a large horizontal aperture to enable measurements under conditions ranging from single-bunch head-on collisions to multi-bunch collisions with a horizontal crossing angle of up to 4 mrad; and, a segmented readout to provide direct information on beam characteristics at the IP. We review the design and performance of this device and discuss its application to machine tuning and performance studies.

INTRODUCTION

With the conversion of CESR to low energy operation by the addition of a dozen superferric wigglers [1], the need for improved CESR-c luminosity tuning tools with minimal systematic bias has become apparent. In particular, the need to rapidly optimize luminosity over a range of operating energies places a high value on reliable tuning tools.

Calibrated CESR luminosity information is provided by the CLEO detector. The CLEO trigger system provides a real-time luminosity rate by measuring back-to-back showers from Bhabha events in the CLEO Endcap Calorimeter. The endcap cross section ($\sim 250\mathrm{nb}^{-1}$ for $\mathrm{E}_{cm} = 3.77\mathrm{GeV}$) is calibrated against the CLEO Barrel Calorimeter whose cross section is understood at the 1% level [2]. Counting rates of $\sim 25\mathrm{Hz}$ at $\mathcal{L} \sim 10^{32}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, however, are too low for machine tuning. As a result, CESR relies heavily on several indirect measures of luminosity for operator tuning. These include: monitoring the beam-beam coupling by means of the $\Sigma - \pi$ split in the vertical tune spectrum; measuring the betatron oscillation induced in one bunch via the coherent beam-beam interaction when the opposing bunch is excited [3]; projecting vertical beam profiles measured in the CESR arcs to the expected luminosity at the IP. Unfortunately, the above methods are sensitive to non-luminosity effects which can confuse their interpretation during tuning and change significantly when switching operating configurations. An ideal detector would provide the following:

- 1 Hz update rate with $< 1\%$ statistical uncertainty
- Minimal systematic bias for all machine conditions (*ie.*, few percent overall and stable during tuning)
- Operation over the full range of CESR horizontal crossing angles: 0 to -4 mrad
- Operation at $\mathcal{L} = 10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (single bunch)
- Bunch-by-bunch measurement capability

LUMINOSITY MONITOR DESIGN

Several experiments (including PEP-II, KEK-B, DAΦNE, and VEPP-2M) [4] have taken advantage of the $e^+e^- \to e^+e^-\gamma$ radiative Bhabha (RB) process to provide a high rate online luminosity monitor. Photons from RB events are emitted within an angle $\theta \sim 1/\gamma$ ($\sim 0.27\mathrm{mrad}$ @1.88GeV) of the parent particle. At CESR this means that the observed photon distribution is dominated by the beam divergence at the IP as shown in Table 1. The differential photon rate can be written as [5]:

Table 1: RB photon divergences and detector spot sizes (16.1m from IP) for *typical* CESR-c parameters: $\varepsilon_x = 150\mathrm{nm}$, $\beta_x^* = 0.45\mathrm{m}$, $\beta_y^* = 13\mathrm{mm}$, and $\sigma_y^* \sim$ 5–10$\mu\mathrm{m}$.

Beam Energy:	**1.55 GeV**	**1.88 GeV**	**2.50 GeV**
$\theta_{\frac{1}{2},x}$ (mrad)	0.68	0.65	0.62
$\theta_{\frac{1}{2},y}$ (mrad)	0.51–0.84	0.47–0.82	0.43–0.80
$\sigma_x(\mathrm{det})$ (mm)	10.9	10.5	10.0
$\sigma_y(\mathrm{det})$ (mm)	8.2–13.5	7.6–13.2	7.0–12.8

$$\frac{dR}{dy} = \mathcal{L}\frac{d\sigma_\gamma}{dy}\left(e^+e^- \to e^+e^-\gamma\right) \quad (1)$$
$$= \mathcal{L}\frac{4\alpha r_e^2}{y}\left[y^2 + \frac{4}{3}(1-y)\right]\left(\ln\frac{s}{m_e^2}\frac{1-y}{y} - \frac{1}{2}\right)$$

with $y = \frac{E_\gamma}{E_{beam}}$, $s = E_{cm}^2$, and $4\alpha r_e^2 = 2.32\mathrm{mb}$. Integrating this expression for photons above the pair production threshold gives a rate in excess of $100\mathrm{kHz}$ at $10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Fig. 1 shows the expected energy deposition for a 1 cm thick slab of scintillator following a 1 inch aluminum window/converter located 16.1m from the IP.

Providing sufficient aperture for the RB photons presents one of the greatest challenges in implementing a detector. In the pre-exiting CESR beam pipe configuration, RB photons would travel for approximately 14m before showering

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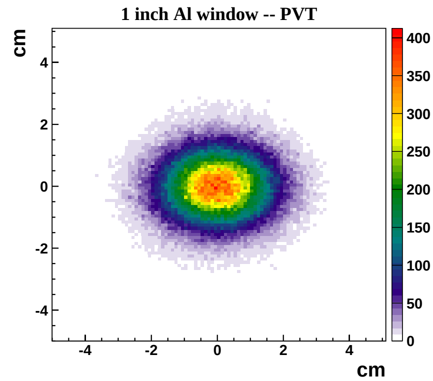

Figure 1: GEANT simulation of the energy deposition in a 1cm slab of scintillator after a 1 inch aluminum window/converter located 16.1 m from the IP.

in the radial outside wall of the chamber. Up to that point, the only aperture limit was due to the $\sim 50\text{mm}$ height of the vacuum chambers. Beyond 14m, the vertical aperture was much more constrained due to a transition to standard CESR elliptical vacuum chamber and the presence of a quadrupole magnet at 15m. By replacing 3 chambers in the 12–20m region with 50mm high flared chambers [6] and replacing the 15m quadrupole with a large bore version [7] capable of accepting the flared chambers, we were able to install a photon window [8] with $+2$ to -7mrad horizontal and $\pm 1.7\text{mrad}$ vertical aperture at a distance of 16.1m from the IP. The modifications were implemented on the CESR vacuum chambers to the west side of CLEO (for easiest access) which means that RB photons from the positron beam are detected.

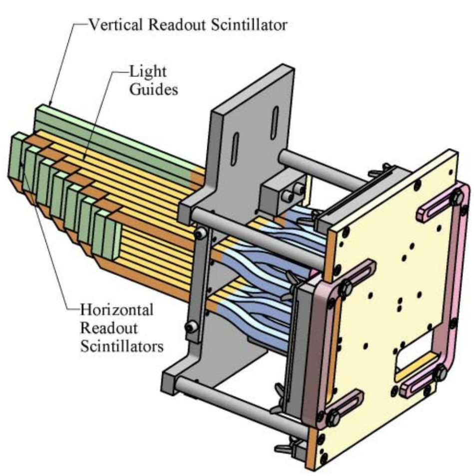

Figure 2: Scintillator detector with 6 horizontal scintillator fingers to provide vertical position readout and a *stair step* arrangement of scintillators for horizontal readout.

After extensive evaluation of vacuum window and detector configurations, a polyvinyl-toluene (PVT) scintillator detector with segmented readout as shown in Fig. 2 was chosen for placement behind a 1 inch thick Al window. The $0.26X_0$ window converts a sufficiently small fraction of the photons so that the detector can operate in a counting mode during CESR-c operations. This also keeps the radiation load low enough that the detector can be expected to survive at least a year of operation at the highest anticipated CESR-c luminosities before needing replacement. Finally, the window design provides sufficient safety margin for synchrotron light source operations at 5.3GeV/beam during which time the detector must be removed. The detector consists of 2 distinct sections which must fit between the coils of a CESR high-field dipole magnet. First, 6 horizontal scintillator fingers ($1\text{cm} \times 1\text{cm} \times 16.4\text{cm}$) span the full horizontal window aperture and provide readout of the vertical photon distribution. 14 shorter scintillators ($1\text{cm} \times 1\text{cm} \times 4\text{cm}$) are oriented vertically. Each scintillator is glued to a light guide which is coupled to its own Hamamatsu 7400U photomultiplier (PMT). The 7400U has a sub-nanosecond risetime capable of resolving the 14ns spaced bunches in CESR. In order to quickly commission a system, initial electronic readout consisted of a 30Hz bandwidth amplifier monitoring the output current of each PMT. Final readout, which is presently undergoing testing, is based on a multi-bunch, 72MHz digitizing module [9].

LUMINOSITY MONITOR OPERATION

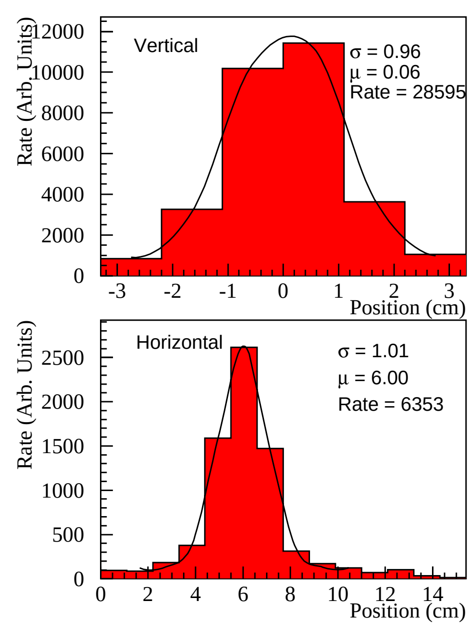

Figure 3: Vertical and horizontal distributions during HEP

CESR modifications and the installation of the Fast Luminosity Monitor (FLM) were completed in early September 2004. Since that time, the detector has been extensively used during 2 CLEO-c runs. Fig. 3 shows vertical and horizontal beam profiles obtained during high energy physics (HEP) running. Fig. 4 shows a scan of a knob which corrects the $\overline{c_{12}}$ coupling element at the IP where the specific luminosity as obtained from the FLM is being monitored. Note that each point represents 10 samples acquired over 0.6 seconds and has a statistical error $\ll 1\%$. Fig. 5 provides a summary of a single day of CESR-c running with a

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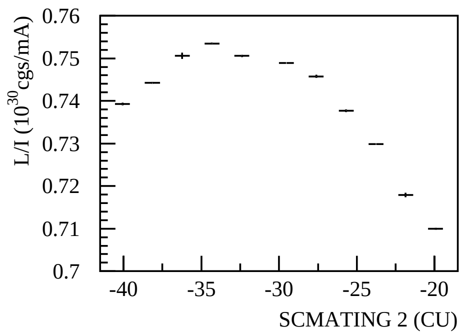

Figure 4: Scan during HEP operation of a knob to correct the $\overline{c_{12}}$ coupling element at the IP using the superconducting IR magnets ($\Delta\overline{c_{12}}/\Delta\mathrm{CU} = 10^{-4}$).

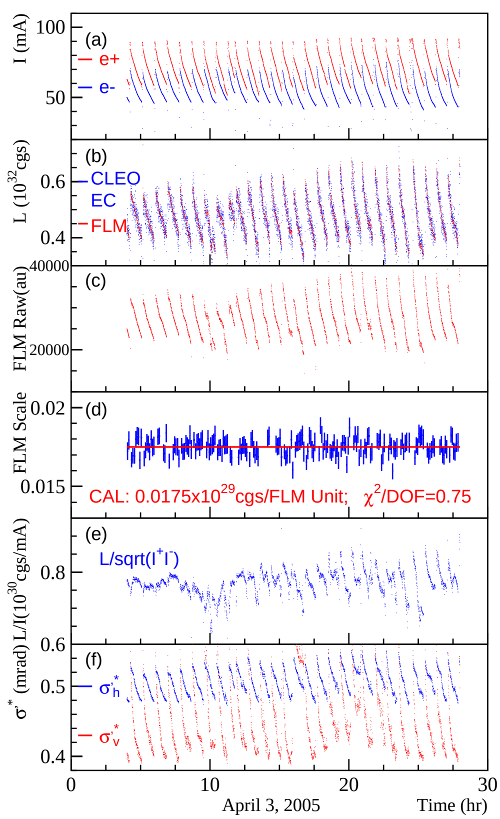

Figure 5: 1-day strip charts showing: (a) CESR currents; (b) CLEO Endcap and FLM luminosity measurements; (c) Raw FLM measurement; (d) Running calibration check of the FLM luminosity scale factor against CLEO (90s int./point; gated for CLEO live); (e) FLM specific luminosity; (f) Horizontal and vertical IP e^+ beam divergences.

relatively wide range of luminosity performance. Plot (b) shows excellent agreement between the CLEO Endcap and calibrated FLM luminosity numbers. Plot (d) shows a monitoring plot of the FLM calibration against the CLEO Endcap throughout the day. Each point represents a 90 second luminosity integration where the error bars are dominated by the uncertainty in the CLEO measurement. An excellent fit is obtained. Plot (e) shows the primary FLM tuning signal employed by the CESR operators while plot (f) shows the positron beam divergence at the IP. For $\beta_v^* = 11\mathrm{mm}$ and $\beta_h^* = 55\mathrm{cm}$, this implies $\sigma_y \sim 4.5$–$6.0\mu\mathrm{m}$ at the IP and a value of ε_h centered around $\sim 140\mathrm{nm}$.

Two sources of detector backgrounds have received special attention. The first is gas bremsstrahlung background from the positron beam. We have measured this to be quite small, at the 1% level, because of the good vacuum found at the IP and the short distance over which the positrons point towards the FLM detector. Secondly, an operational issue has arisen where tuning that causes a drop in electron lifetime leads to showers entering the FLM from the rear. These showers can contaminate the luminosity signal at the few percent level when using the 30Hz bandwidth PMT current monitoring. Fortunately, these showers are out of time with respect to the RB photons and preliminary tests of the bunch-by-bunch readout indicate improved rejection of this background by a factor of 15. On the other hand, e^- showers during injection are the source of a broad signal throughout the detector which is very useful for channel-to-channel gain calibrations.

The FLM has proven to be a useful tuning tool for CESR-c operations. It has functioned stably and reliably since installation. With final implementation of its bunch-by-bunch readout capability, we expect it to continue to play a key role in optimizing and understanding CESR-c luminosity performance.

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