BEAMSTRAHLUNG MONITOR FOR SLC FINAL FOCUS USING GAMMA RAY ENERGIES*

GIOVANNI BONVICINI

University of Michigan, Ann Arbor, Michigan 48109

CLIVE FIELD

Stanford Linear Accelerator Center, Stanford, California 94305

ADOLF MINTEN

CERN, Geneve 23, Switzerland

Abstract

Features of the beamstrahlung flux from the SLC interaction point are discussed, and intensity estimates given. A Čherenkov detector intended to monitor the flux is described.

1. Introduction

The beam collision conditions during the initial tuning and operation of the SLC are likely to fall in the following ranges: transverse beam size σ_x, σ_y $= 2 - 10$ microns, longitudinal size $\sigma_z = 1$ mm, flux $N = 1 - 5 \times 10^{10}$ per pulse, beam divergence 200-300 microrad. The magnetic field of one beam as felt by the colliding bunch can be in the range of 10^2T, and the two bunches will, in general, deflect and disrupt each other. As this happens, there is a brief, strong burst of high energy synchrotron radiation, commonly called beamstrahlung.

The instantaneous emission probability follows classical synchrotron radiation formulae.[1] These must, however, be integrated over the spatially varying fields within the bunches. The energy emitted by beam 1 in collision with beam 2 is

$$W = \frac{0.22\ r^3\gamma^2 mc^2\ N_1\ N_2^2}{\sigma_x\sigma_y\sigma_z} \propto \frac{LN_2}{\sigma_z}$$

where r is the classical radius and m the mass of the electron, γ the Lorentz factor, and L the luminosity per collision.

The spectrum of the radiation is easiest to treat numerically. However, the median or critical energy E_c is $3\ \hbar c\gamma^3/2\rho$, ρ being the radius of curvature, and at high energy the spectrum has the form $\xi^{\frac{1}{2}}\ \exp(-\xi)$, where $\xi = E/E_c$. Also at high energies the emission cone angle $< 1/\gamma$.

A numerical integration of the effect of the two colliding bunches has been carried out. A version of the beam disruption program of R. Hollebeek[2] was modified to determine in each step the local curvature and local photon emission. The photon angle was approximated by the local cell direction. The effects of finite beam divergence were taken into account separately[3]. Estimated yields typically fall in the range $10^6 - 10^{10}$ gamma rays with energy above 20 MeV per pulse.

The deflection of the two beams caused by an offset between them results in the beamstrahlung cone sweeping through the full range of the angular deflection. The angular shift in the center of the beamstrahlung distribution is illustrated in Fig. 1, which follows work of Bambade[4]. If this shift were to be measured, it would provide an independent means of monitoring the interaction point beam-beam steering. The beamstrahlung gamma ray flux is effectively contained within the divergence envelope of the charged beam ($\sigma \simeq 300$ microrad); consequently, it is possible to monitor the effect only after the charged beam has been deflected. The only location is at 40 meters from the interaction point, where the charged beam pipe is just outside the 1 mrad. divergence cone from the interaction point. Of course, the region is also subject to synchrotron radiation from the 1.2T deflecting magnet. The critical energy of the synchrotron radiation is 2.3 MeV, and the flux above 100 keV into a beamstrahlung monitor at this point is 10^{12} gamma rays per pulse (for 5×10^{10} electrons). This corresponds to dose rates of 10-100 R per second for devices in the synchrotron radiation beam.

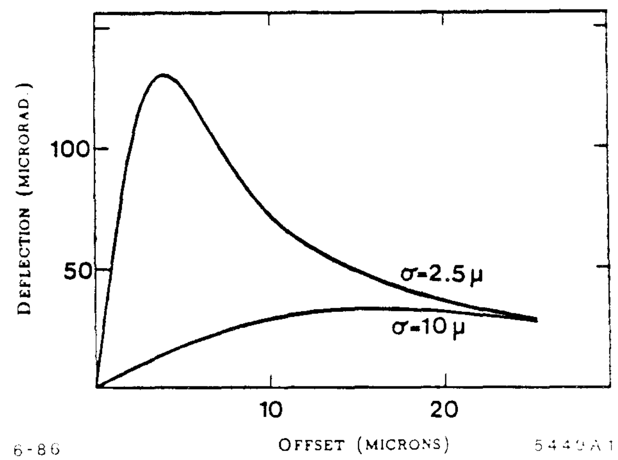

Fig. 1. Deflection of the mean beamstrahlung angle caused by the offset between the charged beams. Beam widths of 2.5 and 10 microns are illustrated.

A plate is used to convert 3% of gamma rays (at 50 MeV) to e^+e^-pairs, without introducing severe multiple scattering. A threshold energy selection of about 25 MeV is then applied to the electrons by using a gas with a refractive index of about 1.0002 as a Čherenkov medium.

It is crucial to select a gas which will not scintillate under the intense bombardment of low energy electrons. From this point of view the gas of choice is ethylene[5], operated at about 0.3 bar. It remains to be ascertained, however, whether radiation effects on ethylene may be deleterious.

General scattered radiation, particularly of photons, is a potentially serious source of background in the light-sensitive element of the device. For this reason, ionization-sensitive techniques are avoided, and the light is collected by photomultiplier tubes. Performance curves in terms of photoelectron yield are shown in Fig. 2. The tube envelopes and gas volume windows will be shielded as far as possible with the help of a convoluted light path.

*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

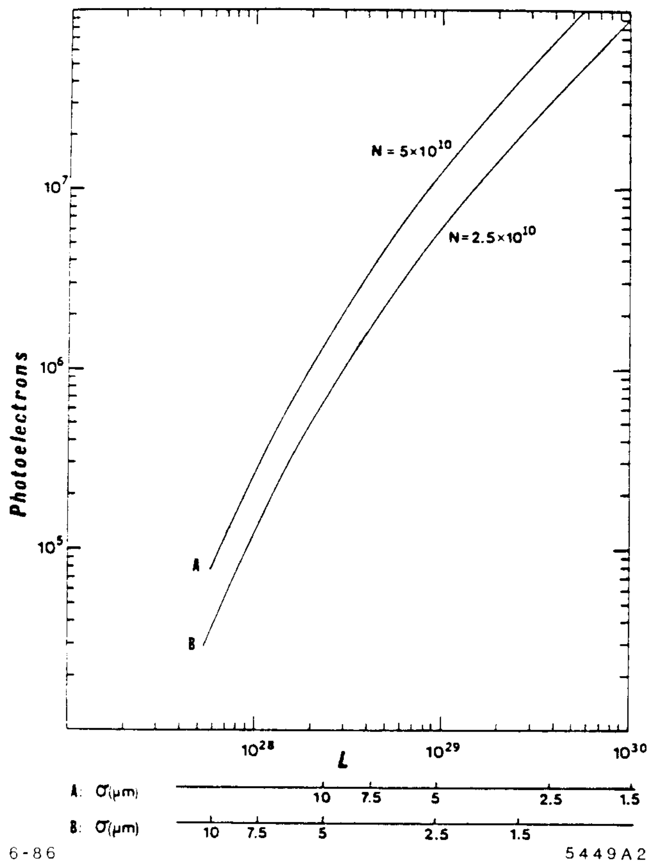

Fig. 2. Photoelectron yield against luminosity L for head-on collisions at 120 Hz. Curve A is for bunch populations of N=5 $\times$ 10^{10}; curve B is for N=2.5 $\times$ 10^{10}. The horizontal axes corresponding to A and B are beam widths in microns.

A concave metal mirror is used to image rays from the converter plate, by way of secondary mirrors, on to the photomultiplier tube plane. This eliminates the smearing effect of multiple scattering in the converter (Fig. 3).

Initially a cylindrical mirror will be used to compress the image on to a single line of P.M. tubes. The tubes will measure the total light yield and also measure the position of the light spot in one axis.

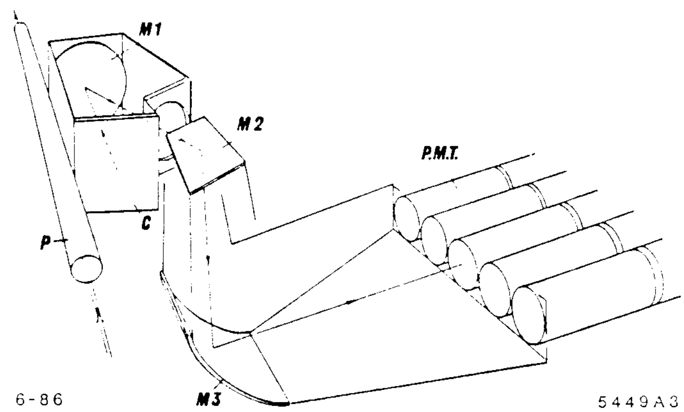

Fig. 3. A schematic cut away drawing of the detector. P-electron beam pipe, C-converter, M1,2,3 - mirrors, PMT-photomultipliers.

It is expected that the device will be sensitive to beamstrahlung cone deflections of 5 microradians (compare with Fig. 1), even for luminosities below 10^{28}.

The electronics will be conventional, apart from the need to encompass a dynamic range greater than 10^4. This is achieved by measuring the charge from the photomultiplier twice, once with an extra gain factor of $\sim$ 20. This makes it possible to fit the desired dynamic range to the limits imposed by photomultiplier linearity at the typically low gains needed, environmental R. F. noise, and ADC charged sensitivity limits. The beam deflection calculation is made pulse by pulse from the ADC values, using a dedicated microcomputer.

In summary, the technique is expected to provide pulse by pulse information about variations in the steering and bunch width conditions at the interaction point.

References

1. J. D. Jackson, "Classical Electrodynamics", Wiley, 1975. Matthew Sands, SLAC-121, November 1970.
2. R. Hollebeek, Nucl. Instr. Methods 184, 333 (1981).
3. R. Hollebeek and A. Minten, SLAC-CN-301, June 1985.
4. P. Bambade, SLAC-CN-303, June 1985.
5. J. Heintze et al., Nucl. Instr. Methods 138, 641 (1976).