ESTIMATES OF THE SYNCHROTRON RADIATION BACKGROUND IN LEP EXPERIMENTS

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Summary

An outline is given of the simulation programs used to estimate the synchrotron radiation background to be expected in the interaction regions of LEP. Before the introduction of collimators, 10^{13} photons/sec of energy above 10 keV fall on the vacuum chamber within ± 3.5 m of the crossing. A scheme of collimators to intercept direct and scattered photons from the vacuum chamber walls is described and examples of the results given. With LEP beams of 55 GeV and design performance, it is expected that the total rate of photons can be reduced by at least seven orders of magnitude. In the central region of an experiment (± 2.5 m), the rate can be kept below 10^5 photons per second by careful adjustment of the collimators to balance photons back-scattered from the vacuum chamber walls and those from the collimators themselves.

Introduction

At the top energy of the initial phase of LEP (55 GeV), the two beams will radiate a total of 1.6 MW of synchrotron radiation photons [1]. In spite of the measures taken in the general layout of the machine, with the experimental insertions in the centre of very long straight sections and a low field bending magnet at the end of the arcs (Fig. 1), far too many of these photons will strike the vacuum chambers of the high energy physics experiments, unless additional precautions are taken. A number of collimators are needed and, in order to find an optimum layout, Monte-Carlo type programs, described below, have been used to generate and track photons from all the relevant magnetic elements in the region of the experiments. In the case of the quadrupole magnets, this requires assumptions concerning the beam profiles and of course beam intensity. In the following, the circulating current has been assumed to be 3 mA in each beam and the expected emittances have been increased from 52 to 75 nm in the horizontal plane and 2.1 to 4.8 nm in the vertical plane. This is to allow for beam-beam effects which have not been taken into account in the design emittances [1] and which may very well give the LEP beams much higher density tails [2] than in the normal Gaussian distributions used in the simulations.

Photon Background Simulation

Two Monte-Carlo codes were developed independently at CERN to simulate the photon background in LEP experiments [3,4]. The first program is a pure Monte Carlo approach, allowing for multiple photon reflections, but produces limited statistics because of its inherent inefficiency. The second program instead uses the concept of superparticles. It allows for one photon reflection only, but renders high statistic runs feasible. A further difference of the two programs lies in the detailed treatment of photon reflection. The two programs agree in their results to within a factor of two.

In both programs electron starting co-ordinates are selected randomly out of the four-dimensional transverse phase space at the interaction point and are projected by transfer matrix techniques to the end of the region of interest (Fig. 1). Here electrons are turned back and tracked through the individual magnets towards the interaction point and beyond it. For this purpose, quadrupoles are split longitudinally into slices. At the centre of each slice, the electrons are made to radiate photons according to the

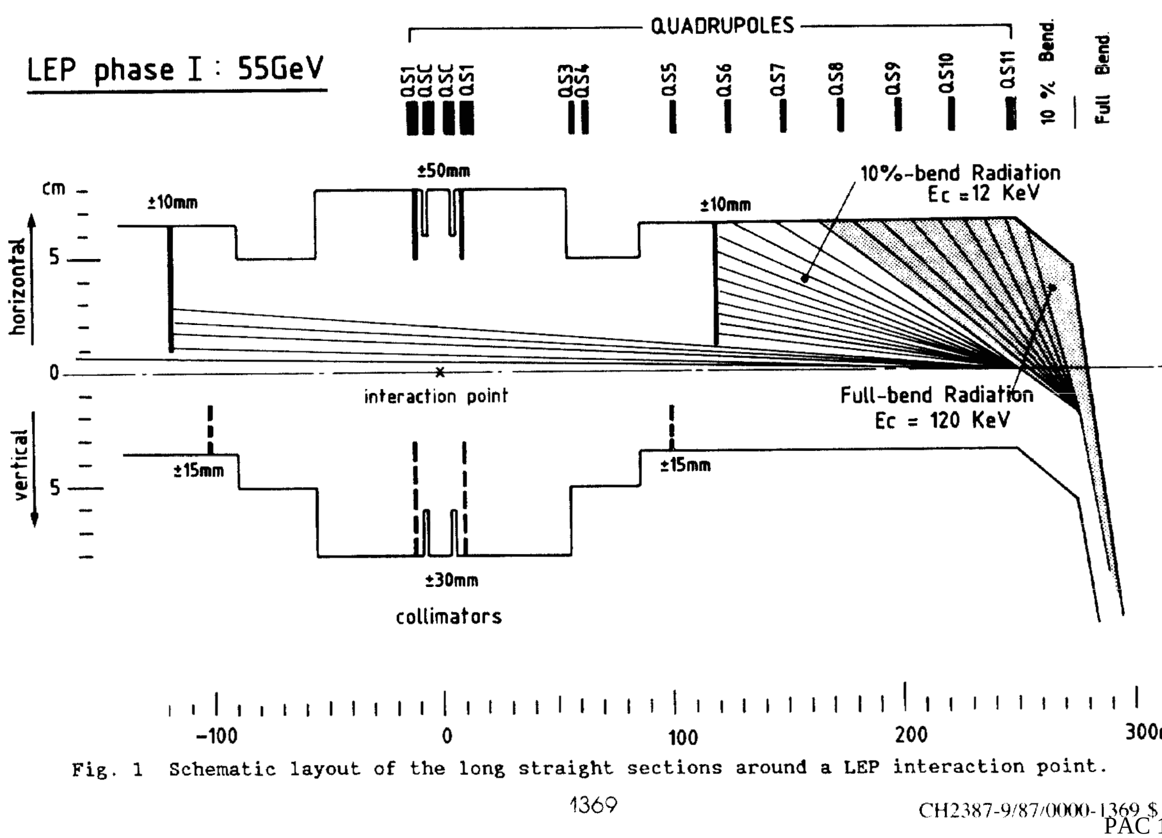

Fig. 1 Schematic layout of the long straight sections around a LEP interaction point.

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magnetic field seen on their orbit at this point.

As the major contribution to the synchrotron radiation spectrum created comes from electrons that populate the outer part of the phase space volume, the electron initial co-ordinates are randomly chosen according to flat distributions along all four axes within an ellipsoid of maximum extent of typically eight standard deviations of a Gaussian distribution. The intensity of these "superelectrons" are then normalized to Gaussian or (optionally) exponential beam distributions. A minimum of 1000 superelectrons are needed to represent adequately the beam distributions.

Photons are created according to the synchrotron radiation spectrum [5], which is completely defined by the electron energy and local magnetic field. Photons are emitted in the direction of the electron orbit at the centre of the quadrupole slice. Hence, the minimum number of quadrupole slices required is governed by an adequate representation of the photon angle distribution. In one program a number of photons are created with energies chosen randomly and weighted according to the energy spectrum, while in the other, computing time is saved by grouping together the radiated photons into typically 10-100 keV photon energy bins. These photons or "superphotons" are tracked further through the system until they either reach the end or are reflected from the vacuum chamber or a collimator surface.

The photon reflection probability and energy loss are calculated from the incident photon energy and angle, taking into account the characteristics of the scattering material. Coherent and incoherent scattering and photon absorption have been included. Figure 2 shows reflection probabilities for backward scattering from some typical materials as a function of the photon energy. Clearly, high Z materials are preferable, in particular for collimators close to the experiment which tend to become important sources of back scattering.

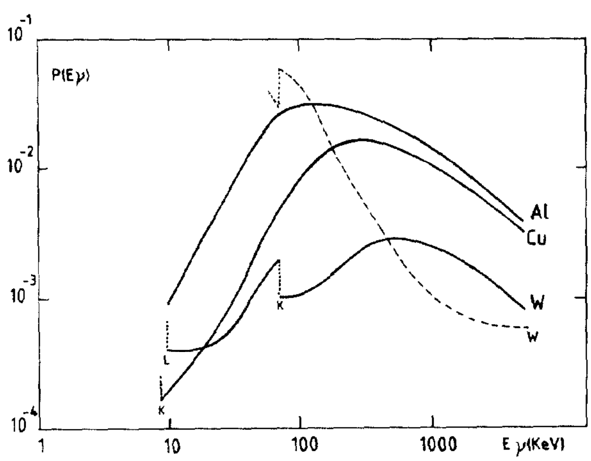

Fig. 2 Backward reflecting probabilities for Aluminium, Copper and Tungsten.

However, heavy materials have the disadvantage of a very high fluorescence yield, and emit photons with relatively high energies. This makes it necessary to plate collimator surfaces with several layers of successively lighter materials, to absorb these fluorescent photons. The fluorescence emission from a tungsten absorber surface (59.3 keV photons) for an incoming photon of energy Eg is indicated by the broken line in Fig. 2. In the 100 keV photon energy region, this probability reaches several percent. In one of the programs [3] reflected photons are further tracked, either towards the experimental vacuum chamber or optionally until a second reflection occurs. In the other program [4] the probability for a hit is calculated analytically by integrating the reflection probability over the target chamber acceptance seen from the photon reflection point.

Estimated Background without Collimators

Table 1 shows the number of photons estimated by means of the programs which can fall directly onto the ± 3.5 m of vacuum chamber between the low-beta quadrupoles where the experiment will be installed. Because of the 22 m long low-field (10 %) bending magnets at the end of the arcs (Fig. 1), none of the 3×10^{15} photons per metre per second radiated by the normal bending magnets can reach the region of the experiments without scattering at least once on the vacuum chamber walls. The critical energy of the photons from the low-field magnets is 12 keV at 55 GeV, while the average energy of the photons from the quadrupoles is approximately 90 keV. In addition to these direct photons some 2×10^9 photons/sec are scattered from the surrounding ± 250 m of vacuum pipe before falling on the vacuum chamber in the experiment.

Source	Photon per second ($E\gamma$ > 10 keV)	
	No collimators	With 100 m and 120 m collimators
Direct from 10 % bend	2×10^{13}	0
Direct from quadrupoles	8×10^{11}	2×10^8
Scattered from ± 250 m	2×10^9	1.5×10^7

Table 1 : Estimated Background Rates (two 3 mA beams of 55 GeV, expt. vacuum ± 3.5 m).

Collimators to remove direct Photons

The same programs were used to optimise the positions of two pairs of collimators, horizontal and vertical, which while removing all direct photons from the low-field bending magnets and most from the quadrupoles are sufficiently far away from the experiment not to significantly increase the number of photons reflected into the experimental region.

Table 1 also gives the estimated rate of direct (mainly from QS 3 and QS 4) and scattered photons with horizontal collimators at 120 m and vertical collimators at 100 m, of full aperture 20 mm and 30 mm respectively. The rates depend mainly on the horizontal collimator setting which must have an aperture of less than 50 mm, in order to intercept direct photons from the low bending magnets. As can be seen the total rate is still above 10^8 photons per second, which is considered to be at least two orders of magnitude too high. In particular, since it must not be forgotten that with any misalignment of the beam with respect to the axis of a quadrupole magnet, the beam passes through a higher magnetic field and more higher energy photons are radiated. The rates of Table 1 correspond to the lowest backgrounds to be expected from a perfectly aligned machine. It is assumed that it will be possible to limit the LEP beam tails to less than 10 σ_H and

20 σ_V respectively with collimators in the arcs [6] so that the presence of collimators upstream of an experiment at similar openings do not create electron background problems.

These collimators have the additional role of reducing off-momentum electron backgrounds originating from gas bremsstrahlung in the arcs and straight sections.

Collimators to reduce reflected Photons

To further reduce the backgrounds from direct and scattered photons, two additional pairs of collimators, horizontal and vertical, were introduced and their location and aperture optimized. At this point, it is useful to distinguish between two parts of the target vacuum chamber. The central part (± 2.5 m, Ø 160 mm) that is shadowed from direct photons by the reduced QSC-chamber (Ø 120 mm) and the forward parts (> ≤ 2.5 m, Ø 120 mm) that are hit by the 2 x 10^8 direct photons per second of Table 1. Scattered photons from different origins arrive at both parts of the target chamber. Most of these photons are backscattered from nearby objects : the QSC-chamber in the horizontal plane, the separator plates (± 50 mm opening) in the vertical plane. They can therefore be intercepted by pairs of collimators located downstream of the QSC-quadrupoles.

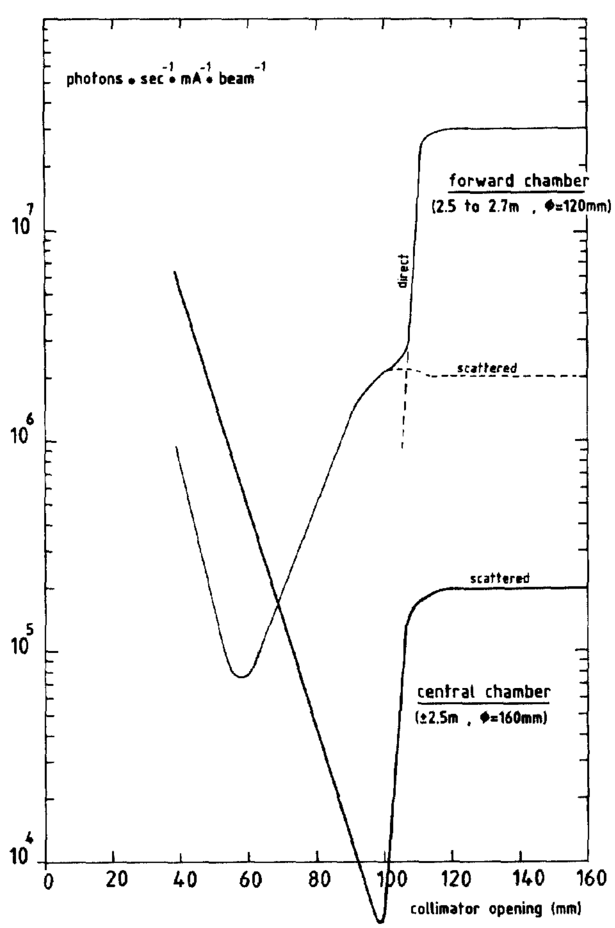

Fig. 3 Photon background rates in experiments as a function of the 8.5 m collimator opening (horizontal)

As these collimators are made of heavy material and are further away from the interaction point, the probability of reflecting photons from these collimators back into the target chamber is at least three orders of magnitude smaller than from the QSC-chambers. However, when closing these collimators to intercept direct and scattered photons, the front face of the downstream collimator is hit by a rapidly increasing number of photons, until, in spite of its low reflecting probability, it becomes the dominating backscatterer and limits the collimation efficiency. This is particularly true in the horizontal plane (Fig. 3), but will also become important in the vertical plane in the case of large vertical emittances (large coupling) or strong vertical beam tails, due to beam-beam effects.

An optimum opening of the "near" collimator exists, at which the reduced QSC backscattered flux and the increasing backscattered flux from the collimator add up to a minimum. This minimum level furthermore depends on the distance of the collimator position from the interaction point. Again an optimum distance can be found [3], the choice of which, however, is largely restricted by installation constraints.

Figure 3 gives results obtained with the simulation program [4] for near collimators placed at ≤ 8.5 m from the collision point for nominal low-beta optics. A second location at ± 15 m is available, optimized for the optics foreseen for initial LEP running [7].

In order to eliminate direct photons on the forward chambers, the horizontal collimators have to be closed to an aperture of about 100 mm (± 15 σ_H), which is also the optimum setting for background ˆvp,6; reduction in the central region. The forward background could be further reduced by closing the horizontal collimators below 100 mm, but this quickly worsens the central background. For the calculations of Fig. 3, the far collimator pairs have been set to their nominal openings reported above, while the vertical collimators at ± 8.5 m were at 60 mm (± 35 σ_V).

The introduction of these additional near collimators reduces the total photon background to the experiments by a further factor of about 100. Due to the large aspect ratio of 25 between horizontal and vertical LEP beam emittances, the photon background to experiments depends mainly on the horizontal beam emittance and increases nearly exponentially with ε_H . The energy spectrum of the background photons after collimation has a mean value of 96 keV with a long weak tail of higher energy photons up to 1 MeV. It should be mentioned that the results of Fig. 3 include only singly reflected photons. An estimate of background rates due to doubly scattered photons gives a level of a few 10^4 photons/(sec x mAx beam). Therefore, in practice, the sharp minimum in the central chamber background will be filled up with multiply scattered photons.

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