ELECTRON BEAM COLLIMATION AT LEP ENERGIES

Georg von Holtey
European Organization for Nuclear Research (CERN)
CH-1211 Geneva 23, Switzerland

Summary

Beam collimation is required in LEP in order to protect physics experiments from the high rate of outdrifting electrons due to various effects that limit LEP beam life times. Very high collimation efficiencies are required. Detailed studies, including tracking of high energy particles through electromagnetic showers in the absorber blocks have shown that best collimation is obtained when using high-Z material collimators with curved edge surfaces along the beam direction. Collimators that receive the full beam intensity, however, cannot be made from high-Z material because of the very high deposited energy density in 50 GeV electron showers. The optimum solution for this case is two radiation length aluminium jaws with curved edge surfaces plated with 10 µm of gold.

Introduction

The expected high rate of particle losses due to exponential beam decay during a store in the LEP collider presents a threatening background source to physics experiments. Aperture collimation of the high energy electron and positron beams is therefore needed in order to localize the particle losses at predefined positions [1]. As the expected loss rate is of the order of 10^8 Hz, while acceptable background levels are only a few 100 Hz per experiment, an extremely efficient collimation is required.

In LEP three aperture collimator systems are foreseen, initially. One for each transverse plane, located at zero dispersion, plus an additional horizontal system at a large dispersion location, intended to intercept particles lost out of the RF-buckets. The latter will also serve as a high energy beam dump.

The majority of particle losses are expected to originate in the vertical plane due to beam-beam interactions and will spill-out with velocities of less than 100 µm per turn, typically [2]. Therefore, most particles will hit the edge of the vertical collimator, making the required high stopping efficiency more difficult.

In a high energy electron-positron collider, further collimators, apart from the beam collimation system, are required to protect physics experiments from synchrotron radiation photons and bremsstrahlung electrons produced in the long straight sections around experiments. In the following we will concentrate on the aperture collimation system only. The complete collimator system proposed for LEP in phase I and a more detailed description of the photon background protection system can be found in reference [3].

Aperture collimation

Collimation efficiencies have been calculated by tracking high energy electrons through electro-magnetic showers in the collimator block, using the code EGS [4]. An electron is called 'escaping the block' when, after interaction with the collimator material, it re-enters the circulating beam with phase space coordinates and momentum still falling inside the ring acceptance. For the momentum acceptance a safe value of $\Delta E/E = 0.05$ has been taken.

Figure 1 shows the calculated escape probability of 50 GeV electrons through an infinitely wide absorber block as a function of its length ℓ in radiation length (r.l.).

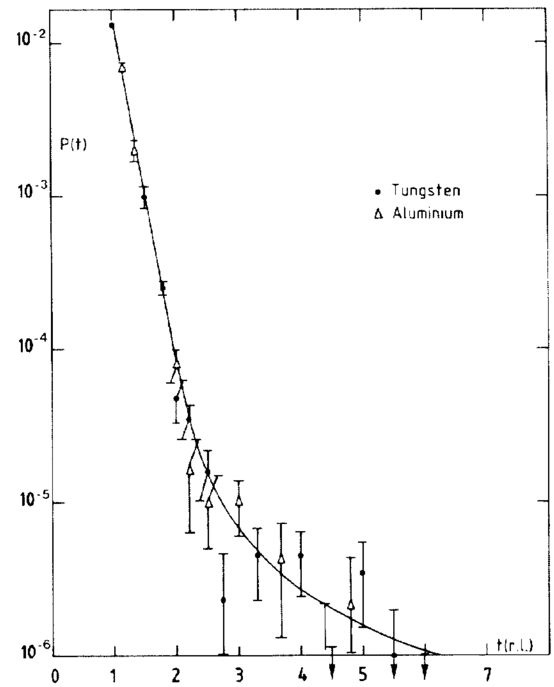

Fig. 1 Punch-through probability for 50 GeV electrons ($\Delta E/E \leq 5$ %).

This punch-through probability falls rapidly down to 10^{-5} over about 2.5 r.l. However, at least 6 r.l. are needed to reach values below 10^{-6}, the statistical limit for EGS calculations. Therefore, where ever possible, 30 r.l. collimators will be used in the following.

The escape probability, however, is substantially increased for particles incident near the edge of the absorber block due to the increased probability of these particles being scattered back into the beam before losing much energy (see Fig. 2).

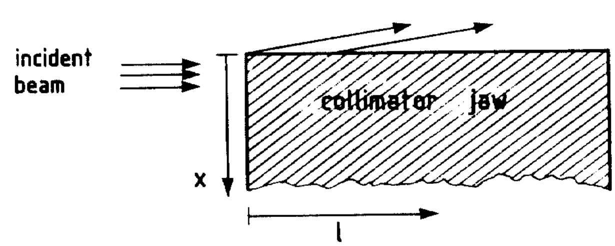

Fig. 2 Edge effect

This "edge effect" is illustrated in Fig. 3 for 50 GeV electrons incident on a 30 r.l. tungsten or aluminium collimator jaw. Escape probabilities P(x) are plotted versus the impact distance x from the collimator edge, expressed in r.l. As multiple

Coulomb scattering and bremsstrahlung are the dominating interactions that can lead to an escape, P(x) is independent of the absorber material when the impact distance is scaled in radiation length.

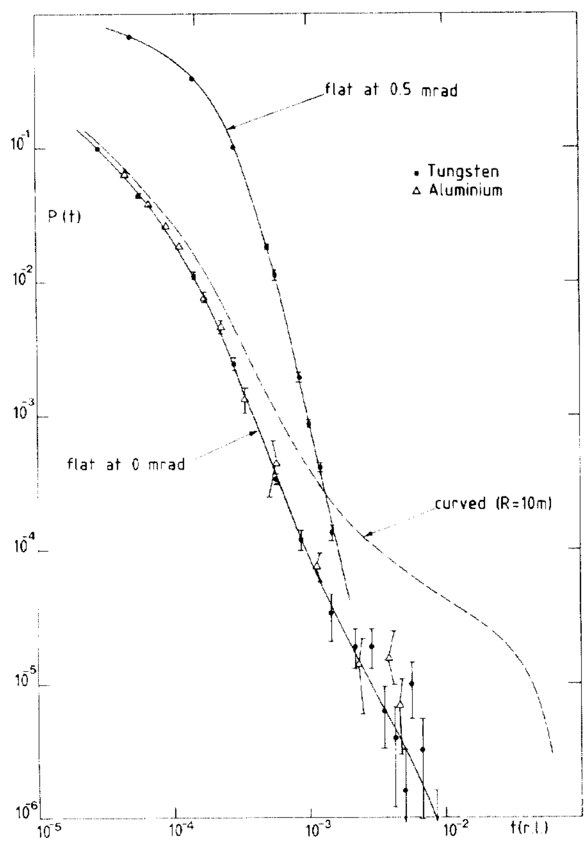

Fig. 3 Escape probability P(x) for 50 GeV electrons from a 30 radiation length collimator edge. ($\Delta E/E \leq 5$ %)

For normal incident particles the escape probability falls below 1×10^{-6}, at a distance from the edge of about 10^{-2} r.l. (see lower curve in Fig. 3). This means, that a tungsten collimator will have a transparent edge of only 35 μm wide, while for a collimator made from aluminium the edge effect extends over 0.9 mm. Clearly, heavy material absorbers are needed if good collimation is required for slowly outspilling high energy beams.

By integrating the curves in Fig. 3 one obtains an average escape probability of 3.9×10^{-4} for an incident beam equally spread over a 100 μm edge of a tungsten collimator. This value would increase to 4.5×10^{-3} with a misalignment of the collimator relative to the incident particles of 0.5 mrad (upper curve in Fig. 3). Although tracking has shown that about half of the escaping particles are not transmitted through the downstream LEP arc (for a nominal collimator opening of $\pm 20\ \sigma_V$), the achieved stopping power is not sufficient, in view of the flux of outspilling particles expected in LEP.

The collimation efficiency can be made insensitive to alignment discrepancies by gently curving the jaw surfaces along the beam direction. A radius of curvature of 10 m for a 30 r.l. tungsten block provides an angular range of the curved surface sufficiently wider than the combined angular spread of misalignments and trajectory slope-variations over the range of collimator openings. It also assures that, for impact coordinates outside the transparent edge, the full absorber length is seen. The escape probability for a 30 r.l. tungsten collimator with a curved edge surface of R = 10 m obtained from EGS calculations is shown in Fig. 3 (broken line). The resulting escape probability averaged over a 100 μm edge is 5.3×10^{-4}, a considerable improvement compared to the straight but misaligned block.

To further improve the stopping power of the collimation system, secondary collimators have been introduced in both beam directions at an optimized position of about 400 m downstream of each primary arc-collimator. The opening of these collimators must be carefully set within the shadow of the primary collimator. A retraction of half a r.m.s. beam width has been used for the calculations. Tracking of the escaped electrons and positrons through the LEP lattice gives 80 % to 95 % probability for them to be intercepted by the secondary collimators, depending on the plane of collimation and on the aperture defined by the main collimator.

Consequently, the probability for 50 GeV background particles to escape a two stage aperture limiting collimator system is of the order of 5×10^{-5} for electrons and positrons incident on the 100 μm wide transparent edge of the primary 30 r.l. tungsten collimator and falls to 5×10^{-6}, if the incident beam is spread over the first millimeter, which constitutes a satisfactory situation.

Beam dumping

When collimators are likely to be struck by the full intensity high energy beams, as is the case in LEP for horizontal collimators located in an arc, they cannot be made of many radiation lengths of a heavy material. The risk of locally overheating the collimator jaws would be too high. A computation [5] of the energy deposition of a 50 GeV electron beam with transverse beam dimensions comparable to LEP has found energy deposition densities in excess of 30 GeV/cm^3 per electron in a copper absorber. With a beam intensity of 2×10^{12} this would heat up the absorber locally well above its melting point.

Collimators which can be hit by the full beam are therefore made of only two radiation lengths of aluminium, which is the best compromise between the two contradicting requirements : i) avoid overheating of the block by showering electrons and ii) ensure that electrons traversing the block will have lost enough energy to fall out of the momentum acceptance. The escape probability for this collimator, has been calculated with EGS, and is shown in Fig. 4 (upper curve).

The punch-through probability ($\Delta E/E \leq 5$ %) for the 2 r.l. Al collimator is 8×10^{-5}, which is just acceptable. But the transparent edge effect of aluminium is far too large. It can be reduced to practically the effect of a tungsten block by plating the surface with 10 μm of gold. As seen on Fig. 4, lower curve, the escape probability then falls rapidly, like for a solid gold edge, up to the layer thickness. Beyond this value it goes smoothly back to the curve for solid aluminium.

Consequently, by plating a low-Z block with a high-Z material, one obtains an electron absorber that combines the low escape rate of a high-Z absorber with the ability to withstand dense high energy beams of a low-Z absorber, because the shower density cannot build up in the midst of a thin layer.

The average escape probability of the plated collimator jaw over the first 100 μm of impact positions is 4.5×10^{-4}, which is a factor 25 lower than for the unplated Al-absorber. As one expects drift velocities of up to 8 mm per turn for the outspilling particles in the horizontal plane, where the dispersion function $D_x = 2$ m, averaging over a few millimeters seems reasonable. After including a surface curvature of R = 15 m for the 180 mm long Al collimator, to become independent of alignment errors, and taking into account the effect of secondary collimators, an overall escape probability of 1×10^{-5} for the horizontal arc-collimator system has been found.

It is foreseen to use this collimator also for systematic beam dumping at the end of physics runs. When the RF-field is de-phased, the 50 GeV bunches drift inside, as the energy loss due to synchrotron radiation is no longer compensated, and reach the horizontal arc-collimator with a rate of transverse displacement of about 3 σ_H per turn. During a physics run these collimators have a typical opening of $\pm$ 10 σ_H. As the physical LEP ring aperture is about twice as large, there is sufficient space left for the particles to reach the collimator jaw on their last turn without hitting the vacuum chamber elsewhere.

Energy dependence

The above results are only weakly dependent on the beam energy. The tendency is towards improved collimator efficiency at higher energy mainly because edge effects become less important with reduced multiple scattering. Beam dumping with a single horizontal collimator system, however, becomes problematic at higher LEP energies. The rate of inward spiralling of the beam, when the RF field is de-phased, increases rapidly from 8 mm per turn at 50 GeV to 32 mm per turn at 80 GeV, with the danger of losing the beam at some unwanted point. Beam dumping at higher energies will therefore require several horizontal dump collimators distributed around the LEP ring.

Hardware requirements

The hardware design of the different collimator types needed in LEP is presented elsewhere in these proceedings [6]. Each collimator consists of a pair of horizontal or vertical jaws. The collimator opening must be remotely controllable with an accuracy of about 10 % of the r.m.s. width of the beams. This accuracy of 50 μm is required for the delicate setting of aperture limits and of secondary collimator openings with respect to primary ones. In order to minimize the radiofrenquency higher order mode losses of the bunched beams on the collimator structure jaws must be fitted with smooth transition pieces.

Acknowledgements

The author wishes to thank C. Bovet for many helpful discussions during the course of this study. The contribution of J.Y. Hemery to the optimization of secondary collimators is greatfully acknowledged.

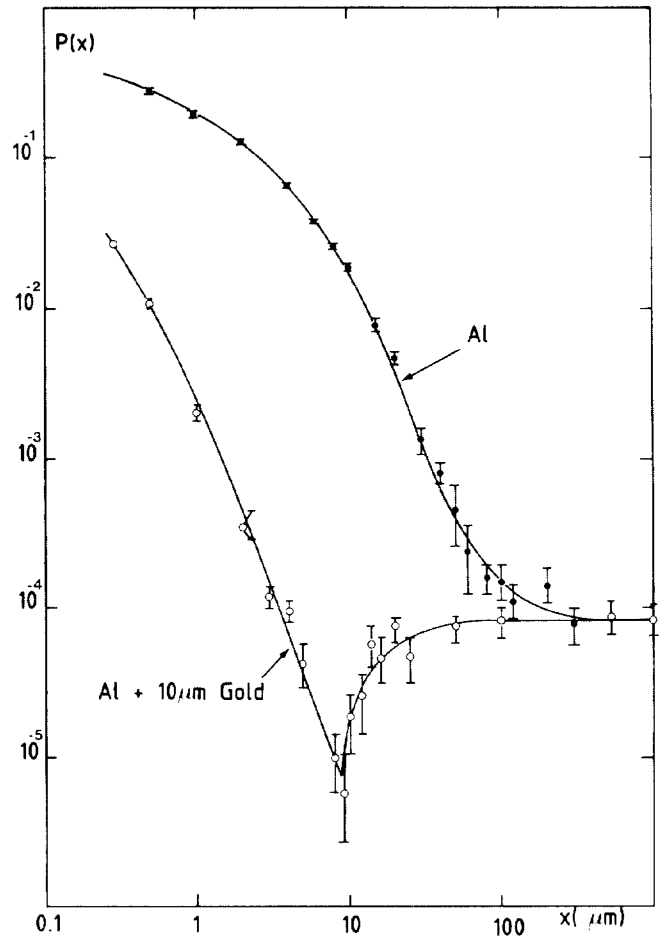

Fig. 4 Escape probability P(x) for 50 GeV electrons from a two-radiation-length Al collimator.

References

[1] T.M. Taylor and G. von Holtey, Dependence of LEP Acceptance on low-beta Insertion Settings, unpublished.

[2] S. Myers, Private communication.

[3] G. von Holtey, LEP Main Ring Collimators, CERN/LEP-BI/87-03.
G. von Holtey and K.M. Potter, Estimates of the Synchrotron Radiation Background in LEP Experiments, Proceedings of this Conference.

[4] R.L. Ford and W.R. Nelson, The EGS Code System : Computer Programs for the Monte Carlo Simulation of Electromagnetic Cascade Showers, SLAC-210 (1978).

[5] P. Sievers and B. Stevenson, EGS Computer Calculations of the Energy Deposition Density of 50 GeV Electrons in Aluminium and Copper, unpublished.

[6] F. Bertinelli and R. Jung, Design and Construction of LEP Collimators, Proceedings of this Conference.