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SYNCHROTRON RADIATION MASKS FOR LEP2

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Synchrotron radiation photon background at LEP detectors for 90 GeV colliding beams have been simulated including radiation from quadrupoles. In order to reduce the photon flux to an acceptable level, the LEP collimator protection system must be improved and synchrotron radiation masks close to the interaction points be added.

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Synchrotron radiation photon background at LEP detectors for 90 GeV colliding beams have been simulated including radiation from quadrupoles. In order to reduce the photon flux to an acceptable level, the LEP collimator protection system must be improved and synchrotron radiation masks close to the interaction points be added.

1. INTRODUCTION

Compared to present conditions, at LEP2 the photon background from synchrotron radiation (SR) will be much higher, reaching rates well above the level acceptable by the LEP detectors [1]. This increase of the photon rate is due to the higher beam energy and in particular the large beam size at LEP2 (ε_x=50 nm). Photons back scattered from downstream vacuum elements now become the dominant SR background. Most of these photons reach the detectors after crossing the electron beam axis and can therefore not be intercepted by standard collimators. However, being scattered from more than 50 m distance, these photons hit the detectors with grazing angles (~2 mrad) and can therefore be intercepted by small absorbing rings placed inside the vacuum chamber close to the experiment. These 'masks' have to be complemented by compact shielding cylinders, outside the vacuum chamber, to absorb photons scattered from the masks themself. This solution was first proposed by the DELPHI Collaboration [2] and has been adopted for LEP2. Due to the location of the SR masks inside the detectors they will have a fixed aperture and are no longer accessible once the detectors are closed. A careful choice of their geometry is therefore imperative to ensure a good performance.

2. SYNCHROTRON RADIATION MASKS

The proposed SR masks for LEP2 are sketched in Fig.1. Mask and outer shield are made of tungsten to optimise their absorption for low energy photons. The length of the mask (≥30 radiation lengths) and the thickness of the shield are defined by the required attenuation factor for the high energy tail of the SR photon spectrum and by the requirement to absorb shower particles from off-energy beam particles intercepting the mask. The inner mask surface is inclined towards the interaction point (IP) by about 1^{o} to avoid forward photon scattering from the mask. Smooth transitions (15^{o}) between mask and vacuum chamber minimise unwanted wake fields. The central chamber and the two masking rings must be aligned parallel to the LEP beams with high precision (0.2 mrad) in order not to loose the shadowing effect.

The longitudinal position and the inner radius of the mask are constrained by several conditions [3]. In order to obstruct the acceptance of forward luminosity detectors as little as possible, the transparent part of the vacuum chamber should not be reduced to below 3.6 m. This defines an acceptance cone of 30 mrad from the IP wherein the cylinder of the outer shield must be fitted. The unavoidable gap between vacuum chamber and shield must be kept to a minimum. The location of the inner tip of the mask should be retracted by at least 0.5 m from the closest end of the shield, in order to protect the experiment in the region where the acceptance for back scattered photons from the mask is highest [2].

The inner mask radius must be small enough to cast a shadow for the dominating grazing incident photons over the complete length of the transparent detector chamber, but must stay outside the very intense direct photon beam that passes through the minimum opening of ±12 σ_x of the nearest collimators, 8.5 m from the IP. Furthermore, and most important, the mask must stay clear the required machine acceptance. A geometrical solution, that fulfils all conditions, is shown in Fig.1. The mask inner tip is at 2.3 m from the IP, while the outer shield starts at 1.8 m.

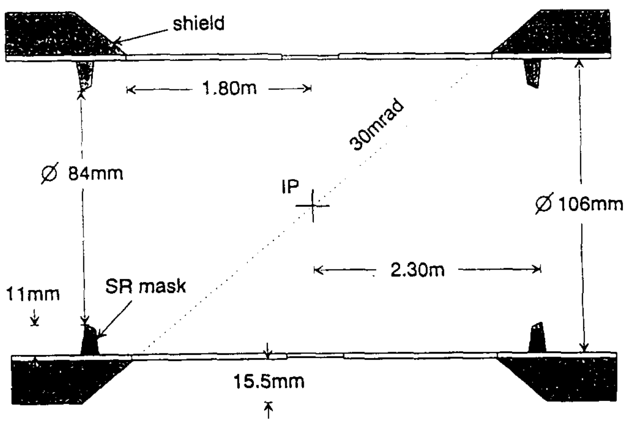

Figure 1: Lay out of SR masks and shielding

3. SIMULATION OF MASK EFFICIENCY

Detailed Monte Carlo simulations of the radiation and transport of SR photons through the LEP2 beam line and the collimator protection system have been performed to study the effect of SR masks. The simulations were done for nominal LEP2 beam parameters (E_{beam}=90 GeV, ε_x=50 nm, ε_y=2.5 nm, β^*_x=1.25 m, β^*_y=0.05 m) and include improvements of the vacuum system proposed for LEP2 [3]: enlarged vacuum chambers in the main region of photon back scattering between 30 and 55 m from the IP and photon absorbers plus tungsten collimators as transition to smaller diameter chambers which are needed to fit through the QS3 quadrupole bore at 56 m.

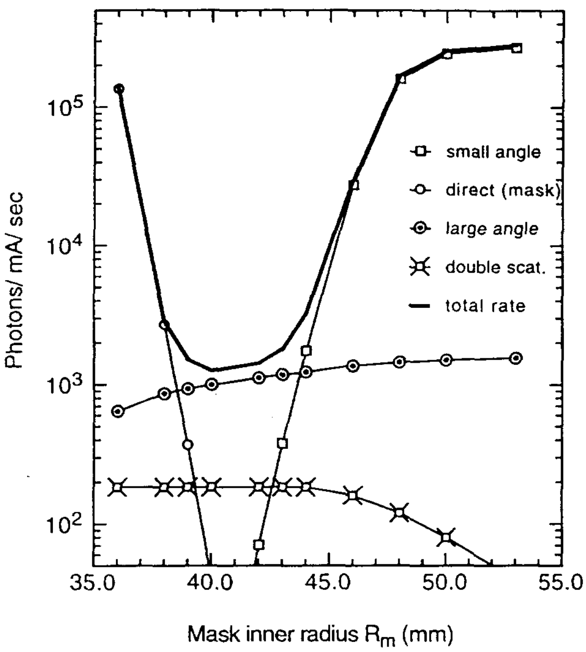

Figure 2. Photon rate versus inner mask radius

Simulated rates of photons reaching the 53 mm radius experimental chamber for different inner mask radii are given in Fig.2. The total background rate is the sum of the components:

(i) 'small angle' photons arrive with grazing angles of ~2 mrad after being back scattered from downstream impacts more than 50 m away . These are the dominant fraction at LEP2 and can be efficiently suppressed with SR masks of R_m<43 mm. The 'small angle' photons are radiated mainly from low-beta quadrupoles on either side of the IP, were the beam dimensions are large.

(ii) 'direct' photons hit the SR masks and are scattered into the detectors. This background rate rises very sharply and dominates for R_m<38 mm. They are radiated from far away quadrupoles.

(iii) 'large angle' photons reach the detectors after being scattered by the nearest collimators, ±8.5 m from the IP. They arrive with average angles of 10 mrad and can only partly be intercepted by the mask. These photons originate from all quadrupoles along the 250 m straight section upstream the IP.

(iv) 'double scattered' photons arrive at the mask after one scattering on upstream or downstream vacuum elements and are scattered a second time from the mask into the detectors.

A SR mask of R_m=42 mm reduces the photon background by more than two orders of magnitude. The remaining background is dominated by large angle photons, the amount of which can be partly adjusted by the 8.5 m collimators. Opening these collimators will reduce the amount of large angle photons, but will also reduce the shadow over the mask for direct photons and therefore decrease the width of the minimum in Fig.2.

The height and width of the minimum is dependent on the longitudinal location of the masks. Moving mask and shield further away from the IP increases the plateau height and reduces its width. Fig.3 compares the simulation results for the optimum mask location at 2.3 m from the IP, leaving a free angular region of ±30 mrad for the forward detectors, with an extreme location at 2.8 m (±23.0 mrad). In both cases the shield starts 50 cm upstream of the inner tip of the mask. The reduction factor is about the same for both cases, but the total photon rate increases by ≈1.5, while the width of the minimum reduces by 35%. The optimum mask radius for the 2.8 m mask is 40 mm and would therefore interfere with the vertical acceptance required for LEP2, as shown in Fig.4. This must be strictly avoided in order to ensure that the masks do not become an unacceptable source of background themselves by scraping into the beam tails.

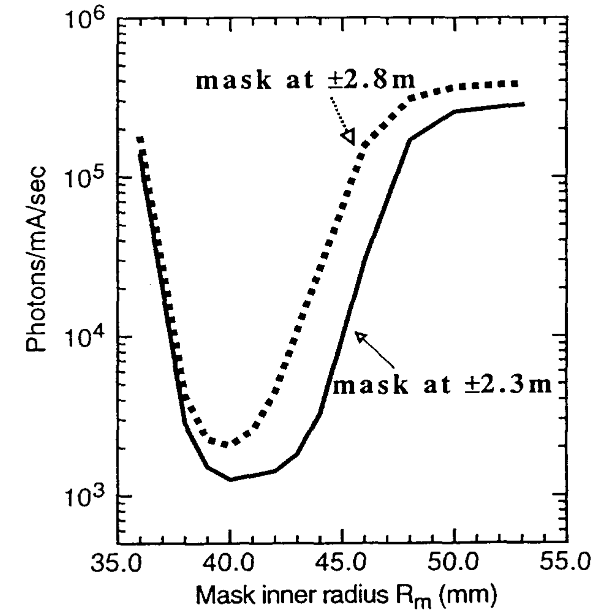

Figure 3: Simulated photon rate for different mask locations

The largest possible distance from the IP to locate SR masks is therefore about ±2.6 m. An elliptical mask would avoid the aperture limitation, but the full shadowing is also needed in the vertical plane, as the small angle back scattered photons from the 55 meter region are rather equally distributed in the two transverse planes.

At the optimum mask radius of R_m=42 mm for the 2.3 m mask the theoretical background reduction factor obtained is 220, more than four time higher than what is needed.

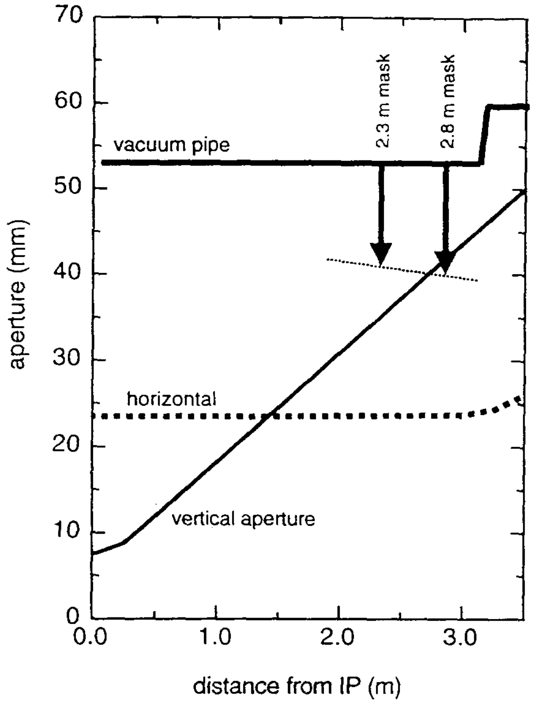

Figure 4: Required machine acceptance around IP

4. Additional Effects

Several additional effects, not included in the Monte Carlo (MC) model, reduce the theoretical protection quality by the SR masks. The most important contributions are: (i) non-zero probability of photon transmission through the mask and shield material, (ii) direct photons from quadrupole radiation that can reach the mask edges if large orbit deviations in upstream quadrupoles exist, (iii) multiple scattered photons that arrive at large angles in the IP, and (iv) misalignments of the mask and detector pipe.

In the MC simulation photons reaching the mask or shield are either scattered from the tungsten surfaces or absorbed. The possible transmission through the absorber material was neglected. Accurate transport calculations of the photon spectra through the mask and a 1.55 cm thick conical shield yield total reduction factors of 500 for the 2 mrad photon family and 1.5 for the large angle component. This is comparable to the results from the MC simulation, supporting the used approximation. However, the transmission probability calculated for direct photons, which hit the inner edges of the masks with grazing angles of typically 0.3 mrad is 0.022, and therefore considerably lager than assumed in the MC model. This leads to a steeper increase of the photon background from direct photons and a reduction of the plateau width.

No orbit deviations in the radiating quadrupoles are taken into account in the MC simulations. This can lead to an underestimation of the amount of direct photons reaching the SR masks, which are less shielded by the near collimators against photons radiated on large orbits.

Both effects decrease the width of the plateau between the steep direct photon flank and the rapidly reduced protection against the dominating small angle photon family with increasing mask radius in Fig.2. Consequently stricter requirements must be given to the alignment of mask and experimental vacuum chamber with respect to the beam axis.

The program does not include multiple scattering of photons along the vacuum system (apart from the mask). The contribution from double scattered photons has been estimated to contribute less than 10% to the total background rate.

5. Conclusions

Cylindrical absorbing masks, placed at 2.3 m from the interaction point inside the experimental vacuum chamber, can reduce the very high rate of synchrotron radiation photons at LEP2 beam conditions down to acceptable levels. However, as the masks will protrude into the machine acceptance, great care must be taken in their positioning to ensure that they do not interfere with the circulating beams and shower halo particles into the detectors. Mask and shield are difficult to incorporate into the existing detectors without compromising on forward detector acceptances and without introducing many inconveniences for the detector assembly.

A first test set-up of local fixed SR masks has been installed in the DELPHI detector [4] and gave satisfactory results during the physics runs of 1994.

6. References

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[4] The LEP Working Group on LEP2 Backgrounds, D. Brandt et al, "Proposal for a Synchrotron Radiation Test Mask in the DELPHI Detector", CERN/LEPC93-10 (1993)