PARTICLE BACKGROUND AT LEP WITH HEAD-ON COLLIDING BUNCH TRAINS

H. Burkhardt, G. von Holtey, CERN, Geneva, A. H. Ball, University of Maryland, College Park

ABSTRACT

The vertical closed orbit bumps around the interaction points in LEP, which are needed to separate counter rotating bunches at their parasitic collision points, generate additional particle backgrounds at the LEP detectors. Monte Carlo simulations of photon and electron backgrounds have been performed and their predictions compared with experimental data. This has led to a good understanding of the bunch train specific background sources and allowed efficient protection measures to be devised.

1 INTRODUCTION

Two types of beam-induced backgrounds at the experimental detectors are important in LEP: photons from synchrotron radiation (SR), mainly radiated in the straight section quadrupoles, and off-energy electrons and positrons, produced by beam-gas bremsstrahlung along the last part of the bending arcs and the straight sections. Both background types are influenced by the vertical separation bumps which are needed to reduce long range beam-beam interactions at the parasitic collision points for the bunch train mode of LEP. These bumps are generated by three pairs of electrostatic separators and span over ~100 m on either side of the interaction points (IP). They include several quadrupoles, but leave the beams unperturbed in the region of the strong low-beta quadrupoles close to the IP's [1].

The amount of additional photon and electron background as a function of the bump amplitude has been carefully studied by Monte-Carlo (MC) simulation and has been compared with measurements.

2 SYNCHROTRON RADIATION

The separated electron and positron beams pass through quadrupoles in the bump region off-axis and therefore radiate more and harder SR photons. With fully excited separation bumps at 45.6 GeV four times more photons are radiated along the straight section as is the case with flat beams. In addition, photon fans are generated with larger angles with respect to the beam axis and therefore strike the vacuum system closer to the IP. Above a threshold bump amplitude this can lead to a rapid increase of the photon background rate at the physics detectors. This occurs when SR photons from the quadrupoles inside the bump start to reach nearby vertical collimators and are reflected with high efficiency into the experiments.

The above geometrical explication of the threshold behaviour of the photon rate was confirmed by Monte-Carlo calculations [2]. The MC code 'PHOTON' [3] was modified to include the effects of electrostatic separators. An example of MC results is shown in Fig.1, giving the total photon rate and its main components as a function of the vertical bump amplitude in IP4 (ALEPH). The exponential rise of the photon rate for orbit amplitudes larger than 10 mm is due to back scattered photons from the downstream vertical collimators +CV.QS1 and +CV.QS2, 8.7 m and 21 m from the IP. At large bump amplitudes photons reach the jaws of the upstream collimators -CV.QS1 and arrive at the detectors with high probability after being Compton scattered in the forward direction. The contribution from the horizontal plane is largely independent of the bump amplitude and dominates the background rate for amplitudes below the threshold.

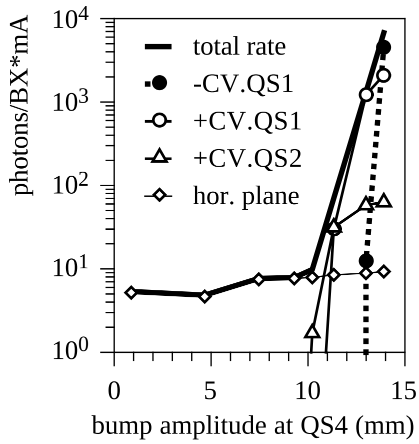

Figure 1: Simulated SR photon rates as a function of the separation bump amplitude in quadrupole QS4. Rates are per 1 mA beam current in one bunch crossing.

Experimental results from a measurement of the photon background rate in ALEPH and DELPHI with vertical bunch trains are reported in Fig.2, and are compared with MC predictions. The experimental conditions for the experiment are described in [4]. Beams were colliding in IP4 and IP8. Bunches were separated at parasitic collision points by the standard electrostatic separator system and photon rates were recorded as function of the maximum separation amplitude at QS4. Photon rates plotted in Fig.2 are normalised "figure-of-merit" numbers from the experiments. Good relative agreement is obtained between measurement and simulation, showing the typical threshold effect.

The actual value of the threshold amplitude depends linearly on the opening of the vertical collimators, in particular on CV.QS1. Smaller collimator openings reduce the bump amplitude at which photons, radiated over the bump, reach the collimator jaw and produce unacceptably high photon background rates. With nominal beam conditions and collimator settings the threshold bump amplitude is 8 to 10 mm, depending on the IP. The maximum achievable bump at 45.6 GeV with full separator strength (100% bump) in IP4 and IP8 is 9.3 mm, while in IP2 and IP6, which have different optics, the maximum (100%) bump reaches 12.6 mm. Larger problems from SR photons must be expected in the latter regions if the maximum achievable separation is needed.

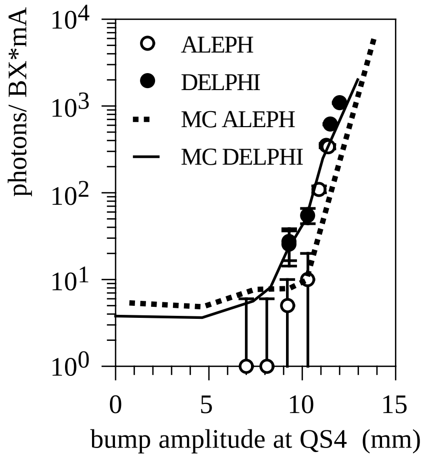

Figure 2: Comparison of simulated (lines) and measured (points) SR photon rates in ALEPH and DELPHI as function of the separation bump amplitude.

The amount of SR-photon background from the separation bump depends also on the electron beam size and transverse density distribution. With bump amplitudes and collimator openings adjusted to safely stay below the photon threshold, large non-gaussian tails or sudden blow-up of the vertical beam size can shift conditions into the high background region and lead to large spikes in the photon background. This phenomenon has frequently been observed during physics coasts with bunch trains in 1995.

The very high photon background rate from large beam displacements through the straight section quadrupoles can in principle be reduced by superimposing anti-symmetric magnetic orbit bumps onto the symmetric electrostatic separator bumps [2]. A superimposed anti-symmetric magnetic bump reduces the excursions of the incoming beams on both sides, while keeping the beam separation constant. The increased radiation generated by the larger excursions of the outgoing beams will produce many more back scattered photons. However, the probability for these photons to reach the detectors is small due to the large distance between the point of impact and the IP, and because more than one scattering is needed to reach the detectors. The effect of anti-symmetric (correction) bumps has been simulated and compares well with measurements [5]. The photon rate could be lowered by more than one order of magnitude by superimposing anti symmetric correction bump of several mm.

However the superimposed anti-symmetric magnetic bumps produce unwanted vertical dispersion and confuse the orbit correction strategy. They were therefore avoided when possible during 1995 physics data taking. Instead, the beam separation around the IP's was chosen to stay below the critical bump amplitude.

3 OFF-ENERGY BEAM PARTICLES

During the 1995 energy scan around the Z^0-peak, where a very accurate luminosity measurement was essential, it became evident that a bunch train specific component of off-energy background was present at the luminosity detectors of the experiments. This background family, clearly detected by OPAL [6], had very distinct features: a sharp peak in its energy distribution around 30 GeV and a concentration in the vertical plane at small radii. These characteristics made it particularly difficult to discriminate off-energy particles from Bhabha events and therefore endangered the envisaged precision of less than 10^{-3} for the absolute luminosity measurement. It was shown experimentally that this background could be considerably reduced by the vertical collimator CV.QS1, see Fig.3, at the cost however of increasing the SR photon background rate.

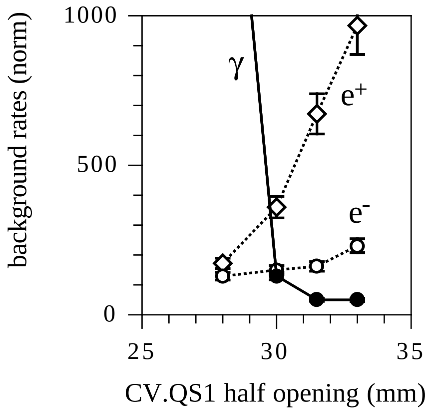

Figure 3: Measured background rates in OPAL as a function of the collimator CV.QS1 opening with 75% separation bump. Off-energy particles (dotted lines), SR-photons (solid line).

Detailed MC simulations [7] showed that the effect was due to beam particles that have lost energy in beam-gas bremsstrahlung interactions in the straight section upstream of the experiment and are then directed by the vertical separation bump into the upper and lower sectors of the luminosity detectors. All the observed special features of this background were confirmed by simulation. The observed changes in the off-energy particles energy distribution are shown in Fig.4. As a consequence of the separation bump, off-energy particles are more concentrated at smaller radii and are focused into two energy bands, one around 30 GeV into the lower detector, and a second, weaker component around 15 GeV into the upper detector. The origin of particles in the high momentum band are the RF-regions around IP6, upstream of the downwards pointing first part of the separation bump for the incoming beam. The 15 GeV band originates from a region, much closer to the IP, along the upwards pointing part of the bump.

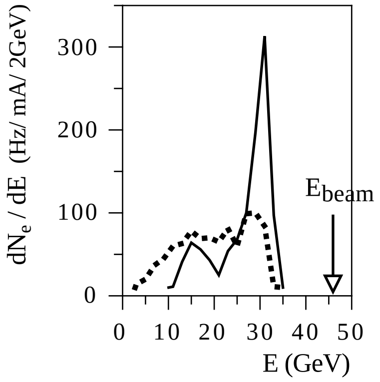

Figure 4: Simulated energy distribution for off-energy particles at the OPAL luminosity detectors. 100% separation bump (solid line), no bump (dotted line).

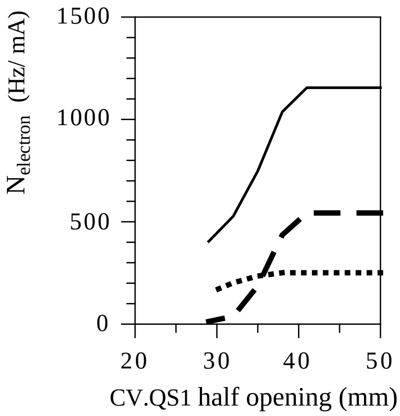

Figure 5: Simulated off-energy rates in OPAL vs. collimator CV.QS1 opening with 100% bump amplitude. Total rate (solid line), high momentum (broken line), low momentum (dotted line).

The good understanding of this background, obtained by simulations, allowed the development of measures to protect against it. As verified by measurements, Fig. 3, the vertical collimators CV.QS1, located 8.7 m from the IP, are very efficient at stopping off-energy particles from reaching the interaction region in the presence of vertical separation bumps. Corresponding simulation results are shown in Fig. 5. The most disturbing high momentum component can be almost completely suppressed with CV.QS1 closed to 30 mm. However, this can only be done, without generating unacceptably high photon background rates, if the vertical separation bump amplitudes in IP6 are reduced to ≤70% of their maximum value and the vertical aperture limits are reduced from $30\sigma_V$ to $26\sigma_V$. During the second part of the 1995 energy scan, this solution was adopted, and gave the expected improvement.

4 CONCLUSIONS

The vertical bumps used to separate bunch trains in the experimental insertions generate particle background at the experiments. Monte Carlo simulation, confirmed by measurements, led to the definition of machine settings which minimised the additional background.

The additional large numbers of SR photons radiated from the quadrupolar fields along the bumps can be prevented from reaching the detectors. This is achieved by keeping the bump amplitudes for the incoming beams, at the crest of the bump in QS4, below a threshold of 9 to 10 mm. This condition was fulfilled for physics runs in 1995 by using 100% of the nominal bumps in IP4 and IP8 and 70% of the nominal bumps in IP2 and IP6. Fine tuning was done by superimposing small anti-symmetric magnetic bumps on the electrostatic bumps when necessary.

The OPAL detector was disturbed by a specific background component coming from off-energy bremsstrahlung particles. In order to suppress this, it was necessary to close the nearest vertical collimator CV.QS1 to <±30 mm and to limit the bump amplitude in QS4. This in turn required the vertical aperture limits to be reduce from $30\sigma_V$ to $26\sigma_V$. In these conditions OPAL was able to achieve the precise luminosity measurement required for the energy scan.

Because the maximum achievable separation at 90 GeV is 5.5 mm, well below the critical amplitude, no additional photon or off-energy background problems are expected with the bunch train scheme for LEP2.

REFERENCES

[1] 'Report of the 1995 Bunch Train Study Group', C. Bovet et al, CERN SL/ 96-12, April 1996

[2] "Synchrotron Radiation Photon Background with Bunch Trains in LEP', G. von Holtey, CERN SL/95-29, July 1995

[3] 'Estimates of Synchrotron Radiation Background in LEP Experiments', G. von Holtey and K.M. Potter, IEEE Part. Acc. Conf., Washington 1987

[4] 'Study of Photon Background with Bunch Trains', W. Herr et al, SL-MD Note 159, Decenber 1995

[5] 'Measurements of the Photon Background at LEP Detectors with Symmetric and Anti-Symmetric Vertical Bumps for Bunch Trains', H. Burkhardt et al, SL-MD Note 143, September 1995

[6] R. Kellog, private communication, OPAL 1995

[7] 'Off-Energy Electron Background with Bunch Trains in LEP', G. von Holtey, CERN SL/95-86, October 1995