OBSERVATION AND SIMULATION OF BEAM TAILS IN LEP

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Abstract

Transverse beam tails have been measured in LEP using scraping collimators and loss monitors. Very significant non-Gaussian tails are present for colliding beams and high beam-beam tune shift. On a lower but still significant level, non-Gaussian tails are also present in the horizontal plane for a single beam. Comparison of measurements with detailed simulations allowed us to identify off-momentum particles produced by scattering processes as a source of significant transverse tails.

1 TAIL SCANS

1.1 Technique

Transverse beam tails are measured at LEP using scraping collimators. The loss rate is measured with loss monitors installed close to some collimators [1]. The loss rates are directly converted into beam lifetime due to scraping. The calibration in lifetime is done for high loss rates, such that the beam lifetime is dominated by scraping and easily measurable as reduction of beam current with time.

1.2 Results

Tail measurements have been done in LEP on many occasions in recent years [1]. The main conclusions from these measurements were:

1. At 45 GeV strong vertical tails were observed with colliding beams.
2. In the horizontal plane on a lower but still significant level, non-Gaussian tails were observed which were present for a single beam and colliding beams.

2 TAIL PRODUCTION DUE TO OFF-MOMENTUM PARTICLES

2.1 Production Mechanism

The results in the horizontal plane pointed to a mechanism other than the beam-beam interaction for the production of tails. Scattering processes were proposed as a source of these tails [1], and have now been studied through detailed simulations and dedicated measurements in LEP where the scattering process with the highest probability is Compton-scattering on thermal photons [2] (photons from the black body radiation of the beam pipe). In this process the scattered electron (or positron) loses some of its energy. If this happens in a region where the dispersion is nonzero, the particle will start betatron oscillations, with an amplitude depending on the energy loss and on the dispersion. This is shown schematically in Fig. 1. The relative energy loss increases with beam energy and reaches about 2 % on average at the present LEP beam energies (around 90 GeV).

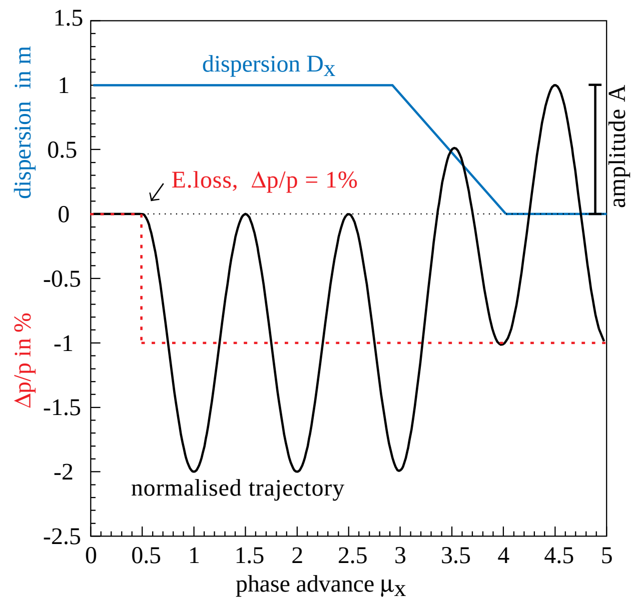

Figure 1: Transverse tail production mechanism: A particle loses some energy due to a scattering process in a region with dispersion. Due to the energy loss it starts betatron oscillations.

If the energy loss is more than 3 %, the electrons are lost locally. For an energy loss between 1 and 3 %, the scattered electrons have very large oscillation amplitudes and are lost within a couple of turns. These electrons contribute to the very far tails. Even if the energy loss is less than the RF bucket height or energy acceptance (about 1 %), the scattered electrons remain at large amplitudes within a damping time (less than 100 turns at 90 GeV).

2.2 Tracking Scattered Particles with DIMAD

To study the tail production due to scattering processes in detail, we started to implement a simulation of these processes in the tracking code DIMAD [3].

The tracking of particles in DIMAD is based on a matrix formalism at first or second order and is done element by element. In addition DIMAD offers the possibility to include other processes such as synchrotron radiation in the tracking. DIMAD can simulate the effects of synchrotron radiation in bending magnets and quadrupoles, for both the systematic part, considering the average energy loss, and the stochastic part by individual photon emission accord-

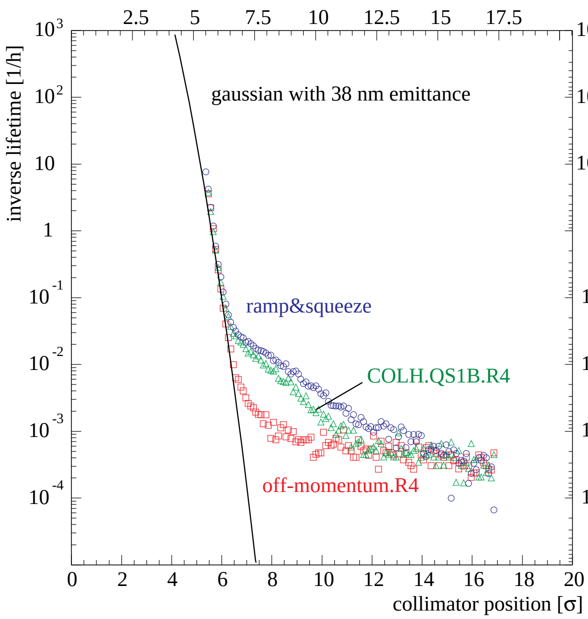

Figure 2: Horizontal tail measurements at 80.5 GeV with different collimator settings. The collimators were moved to a position corresponding to 8.6 on the lower scale of the x-axis, which is in units of 'nominal' σ_{nom} corresponding to 40 nm emittance (used to calculate collimator settings). The top scale is in σ_{meas} corresponding to the measured emittance (38 nm).

ing to different distributions.

For the thermal photon simulation the scattering occurs at random places around the ring. The scattered particles are tracked for several damping times and their maximum excursions at the scraping collimators are stored. Knowing the cross-section for the Compton-scattering, one can then convert the number of particles which would hit the collimator at a certain position to an inverse lifetime and compare the results to the measured tails.

2.3 Horizontal Single Beam Tails

To demonstrate that the horizontal tails consist mainly of off-momentum particles, some measurements were made with different collimator settings. One measurement was done with all collimators at the nominal 'RAMP&SQUEEZE' settings (corresponding to 17 σ for collimators in regions without dispersion and more than 20 σ in regions with high dispersion; σ being the standard deviation of the transverse particle distribution in the beam). Then one collimator in a region without dispersion (COLH.QS1B.R4) was moved close to the beam and the tail scan repeated. This reduced the tails noticeably but not significantly. Moving the off-momentum collimators, which are at a position with high dispersion, to an equivalent position in beam size reduced the tails significantly as shown in Fig. 2.

If the collimator jaw is moved to closer than about 6 σ one reaches the Gaussian core of the beam for which the lifetime due to scraping can be calculated [4]. From this

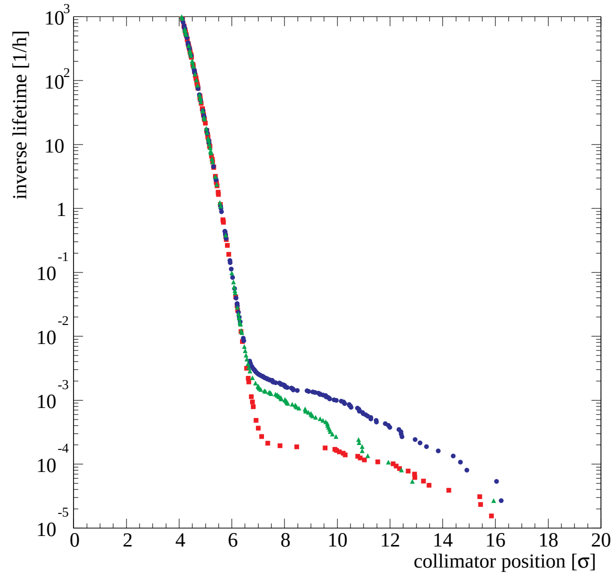

Figure 3: Horizontal tail simulations at 80.5 GeV with the same collimator settings as in Fig. 2.

one can deduce the emittance at a 5 to 6 σ level. For the measurements shown in Fig. 2 we found 38 nm. This method can be used to cross-check emittance measurements from other instruments. As it uses the region between about 5 and 6 σ whereas the other instruments typically use the first 2 σ, it can provide additional information on the beam profile. This proved to be helpful in understanding some problems due to resonances in a low-emittance lattice which was tried in LEP in 1996 [5].

Simulations with the same collimator settings as shown in Fig. 2 were done by tracking particles which undergo Compton-scattering on thermal photons using DIMAD. The results are shown in Fig. 3.

The results from the tracking are in good agreement with the measurements taking into account errors due to the calibration and contributions to the tails due to Bremsstrahlung on the residual gas which was included in a rough estimate but is not yet included in the full simulation.

2.4 Horizontal vs. Vertical Tails

The betatron oscillation amplitude of a particle, in number of σ, after the scattering depends on the energy loss $\Delta p/p$ and the dispersion D_x:

$$N_x[\sigma] = \frac{D_x \cdot \frac{\Delta p}{p}}{\sqrt{\beta_x \cdot \varepsilon_x}} \quad (1)$$

The horizontal dispersion in LEP is about 1 m and the average β-function in the arcs is 81 m. For a horizontal emittance of 40 nm we expect from Eq. (1) that a scattering process resulting in $\Delta p/p = 1$ % will launch the particle to an amplitude corresponding to 5.6 σ.

The same effect also exists in the vertical plane. For most of the ring, the vertical and horizontal β-functions are comparable. The residual vertical dispersion in LEP ($D_y = 0$

by design) is on average about 30 times less than the nominal horizontal dispersion in the arcs. Even if we take into account the emittance ratio $\varepsilon_y/\varepsilon_x = 0.5$ % we expect from Eq. (1) that tail production in terms of σ will be smaller in the vertical plane by a factor of $30\sqrt{0.005} \approx 2$.

2.5 Vertical Tails due to Beam-Beam Bremsstrahlung

We have also started to investigate the effect of energy loss in scattering processes at the interaction point, where the β-function in the vertical plane is very small. The main process to consider is the nearly zero angle radiative Bhabha scattering (also called beam-beam Bremsstrahlung) due to its large cross section and energy loss. For $\beta^* = 5$ cm, a vertical emittance of 0.5 nm and a residual vertical dispersion of typically 3 mm at the interaction point we find that a scattering process with $\Delta p/p = 1$ % would launch particles to 6 σ. We have started to implement a simulation of the energy loss due to beam-beam Bremsstrahlung in DIMAD. First results of the tracking are shown in Fig. 4. They indicated, that some particles can be launched up to the dynamic aperture and then drift even further out into very far non-Gaussian tails, until they hit a physical aperture.

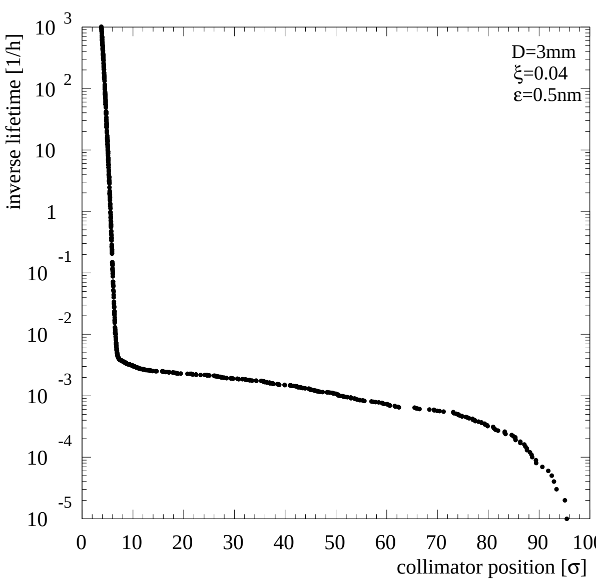

Figure 4: Simulation of vertical tails due to beam-beam Bremsstrahlung for 45.6 GeV, a beam-beam tune shift of $\xi_y = 0.04$ and an emittance of 0.5 nm. The x-axis is in units of σ corresponding to the emittance of 0.5 nm. The physical aperture of LEP is around 90 σ in this units.

3 SUMMARY

Measurements and simulations have shown that the transverse non-Gaussian tails in LEP consist partially of off-momentum particles. Many of these particles are lost from the beam within a few turns. We have identified the production mechanism as energy loss from scattering processes in dispersive regions. The particles are not lost immediately after the scattering, but they continue to travel for typically up to 10 turns at very large amplitudes, often outside the dynamic aperture, which increases their amplitudes even further.

We have started to implement the detailed scattering processes in the tracking code DIMAD. The tracking confirmed that horizontal tails are already present without colliding beams and that the main process in the case of LEP is Compton-scattering on thermal photons. In the vertical plane, tail production can be initiated by residual vertical dispersion at the interaction point and beam-beam Bremsstrahlung.

4 REFERENCES

[1] H.Burkhardt et al. Beam Tails in LEP. In V. Suller and Ch. Petit-Jean-Genaz, editors, *Proceedings of the 5th European Particle Accelerator Conference*, volume 2, pages 1152–1154, 1996.

[2] H. Burkhardt. Beam-Beam and Lifetime. In J. Poole, editor, *Proceedings of the 3rd Workshop on LEP Performance*, pages 117–122, 1993.

[3] R. V. Servranckx, K. L. Brown, L. Schachinger, and D. Douglas. Users Guide to the Program DIMAD. SLAC REPORT 285 UC-28 (A), SLAC, May 1985.

[4] M. Sands. The Physics of Electron Storage Rings. SLAC REPORT 121, SLAC, 1970.

[5] I. Reichel. Dynamic Aperture and Tail Scans. In J. Poole, editor, *Proceedings of the 7th Workshop on LEP Performance*, pages 67–71, 1997.