Beam tails in LEP

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Abstract

Beam tails have been measured in LEP using scraping collimators and loss monitors for separated and colliding beams. Significant non-Gaussian beam tails have been observed with colliding beams for high beam-beam tune shift parameters and bunch currents.

1 INTRODUCTION

LEP has been running for 6 years with beam energies of about 45.6 GeV [1]. Single beam emittances can be rather small: In the horizontal plane ε_x = 12 nm and still two orders of magnitude less in the vertical plane. For bunch currents of 350 μA initial unperturbed tune shifts would be typically 0.08. Significant increase of beam sizes is observed in both planes as result of the beam-beam interaction. A wiggler placed in a region with dispersion (the emittance wiggler) is used to increase the horizontal emittance up to 36 nm i.e. reduce the initial unperturbed horizontal tune shift to about 0.028. This is needed to bring beams safely in collision and to avoid flip-flop and excessive beam-beam tails with background and lifetime problems during standard operation.

Beam lifetimes in LEP are well understood and under normal running conditions completely accounted for by known physics collision processes [2]: Single Beam lifetimes are typically 40-50 hours due to Compton scattering on black body radiation (thermal photons) and beam-gas Bremsstrahlung. In collisions, lifetimes are reduced to about 17 hours due to "loss" of particles in e^+e^- collisions.

Beam-beam tune shift parameters in excess of 0.04 have been reached routinely in operation [3].

Shorter beam lifetimes than expected and bursts of background to the experiments have been observed for colliding beams and high beam currents and have limited the maximum currents that can safely be collided [4]. They are attributed to non-Gaussian tails in the transverse beam profiles, generated by the beam-beam effect.

2 LOSS MONITORS AND TAIL SCANS

A bunch current of 350 μA represents $2 \cdot 10^{11}$ particles and 100 hours lifetime correspond to $5.5 \cdot 10^5$ particles lost per second or about 50 particles per turn. A very high sensitivity to beam tails can be reached using loss monitors close to aperture limits [5]. Scintillators have been installed in LEP at the aperture limiting collimators [6]. Recently, many more loss monitors using PIN-diodes based on a design for HERA [7] were installed close to most collimators in LEP. Figure 1 shows schematically the layout around the main horizontal aperture limiting collimator in LEP, equipped both with scintillators and PIN-diode beam loss monitors. Several measurements using these loss monitors have been performed in recent machine development sessions and are analysed [8, 9].

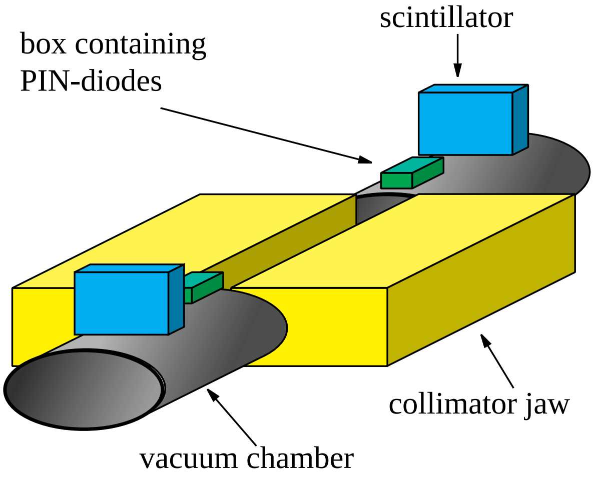

Figure 1: The horizontal aperture limiter with its PIN-diode beam loss monitors and scintillators (schematic).

Measurements were performed by moving one jaw of a collimator closer to the beam in steps. Beam current and beam size measurements were recorded for each collimator setting. The collimators were moved closer until significant lifetime reductions were observed. Lifetimes calculated from beam currents for these points were used to calibrate the loss monitors. This allows to give loss rates directly in terms of equivalent lifetimes. The uncertainty in the absolute calibration is estimated to be about 30%. There is some additional systematic error from noise and saturation for very high and low loss rates:

The PIN-diode monitors are nearly noise-free but give only counts and saturate therefore at one hit per bunch passage. Measurements have been linearised using Poisson statistics [10].

The scintillators use pulse height information and did not reach saturation. Due to noise, these monitors are not sensitive to losses corresponding to lifetimes longer than 10^4 hours.

The two different types of loss monitors are therefore rather complementary.

3 BEAM-BEAM TAILS

Figures 2 and 3 show tail distributions as measured in two machine development sessions. The machine conditions were close to standard physics operation with standard pre-collision tunes set to $Q_x = 90.3$ and $Q_y = 76.2$ and $Q_s = 0.065$. The horizontal emittance is measured using a synchrotron radiation monitor (BEUV). The vertical beam size is calculated using luminosity information. The specific conditions were:

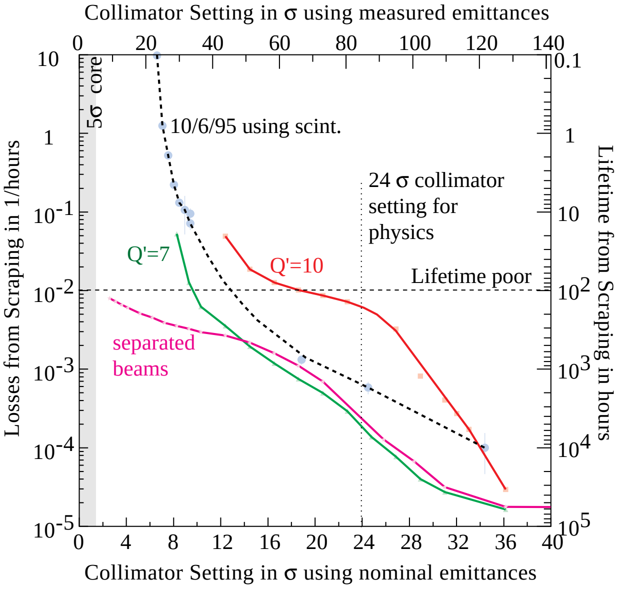

Figure 2: Measured beam tails in the vertical plane.

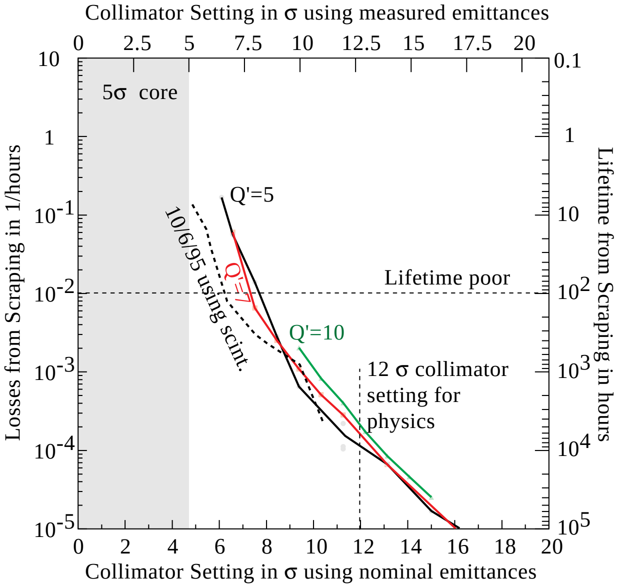

Figure 3: Measured beam tails in the horizontal plane.

1. Fill 2364 on 4-9-94, 4+4 bunches, about 360 μA per bunch, tails measured using PIN-diode loss monitors; emittances were ε_x = 40 nm and ε_y = 0.36 nm, beam-beam tune shift parameters ξ_x = 0.025 and ξ_y = 0.042 . Results are shown as solid lines for different settings of chromaticity (Q' between +5 and +10). In the vertical plane tails were also measured with separated beams.
2. Fill 2724 on 10-6-95, 4+4 bunches, about 250 μA per bunch, losses measured with scintillators; beams colliding, using '95 optics with vertical separation on either side of the interaction regions for bunch trains. Rather unequal beam sizes, about 60 % higher e$^-$ emittances in both planes. e$^-$ beam parameters were ε_x = 44 nm and ε_y = 0.4 nm, with beam-beam tune shifts of ξ_x = 0.025 and ξ_y = 0.035 . Measurements were done for one machine setting with Q'=10 in both planes.

   The results are shown as broken lines. At the end of the second machine development scraping in the vertical plane was continued down to very low electron lifetimes in the order of minutes.

We distinguish between nominal and measured emittances. The nominal emittances are 45 nm for the horizontal and 4.5 nm for the vertical plane. Nominal emittances are very useful to compare collimator settings for various optics and positions around the ring. The values of 45 and 4.5 nm have been used in LEP for the last couple of years and still reflect quite well the maximum beam sizes observed in operation.

The collimator settings in figures 2 and 3 are given in units of σ of nominal beam sizes. In addition, a second x-scale is shown on top of the figures using the measured beam sizes (measured beam sizes of all shown measurements were equal within errors of about 10%). The expected Gaussian core is illustrated as shaded area to 5 σ using the measured emittances. The theoretical lifetime for a Gaussian beam and collimators at 5 σ is below one minute.

At this stage of measurements and analysis we found indications for:

- Non-Gaussian transverse tails in both planes. Far tails and losses corresponding to lifetimes of the order of 10^3 hours were also recorded without colliding beams.
- Very substantial non-Gaussian beams are present for colliding beams in the vertical plane. High chromaticities can increase vertical tails.

4 BEAM LIFETIME FROM SCATTERING PROCESSES

Lifetimes for single beams, separated beams and low-current colliding beams in LEP are well explained by known physics collision processes

- Compton scattering on black-body radiation photons
- Beam-Gas scattering
- Beam-Beam Bremsstrahlung

These collision processes result mainly in off-energy particles. The scattering angles are rather negligible compared to the beam divergence. If the energy loss exceeds the stable bucket height (about 1% for LEP1) these particles will be lost, typically by hitting an aperture limit in a dispersion region.

5 SIMULATION OF BEAM TAILS

The Compton scattering and Beam-Gas scattering can occur anywhere around the ring. Even if the scattering angles are neglected, the combination of energy loss and significant dispersion, as present in the horizontal plane in the arcs of LEP, will generate significant betatron oscillations and result in horizontal tails.

To study this quantitatively, we interfaced a simulation of the Compton-scattering on thermal photons [11] with the detailed tracking code DIMAD [12]. First results indicate, that the far horizontal tails observed in LEP can be largely explained by the scattering on thermal photons.

Extra losses, not explained by the three scattering processes, are seen for colliding beams and high currents. They are generally accompanied by background spikes observed in the experiments and have limited the maximum useful bunch currents at LEP1. Emittance blow-up is observed for colliding beams in LEP in both planes. A wiggler is used to artificially increase the horizontal beam sizes and to avoid flip-flop and excessive tails. With the observation of very substantial vertical tails and the rather lower, constant level of horizontal tails observed so far, we expect that the current limitation in collisions with extra losses and background spikes can be attributed to vertical tails.

We have started to use results and computer codes of beam-beam simulations [13, 14, 15] with the aim to get a better understanding of the processes and main machine parameters involved in generating vertical tails.

6 SUMMARY

At beam energies of about 45.6 GeV, the maximum useful current per bunch in collisions in LEP has been limited by background spikes as observed in the experiments and by reduction in beam lifetime. This can be explained by scraping into non-gaussian tails generated by the beam-beam effect.

We have quantitatively measured horizontal and vertical non-gaussian tails using scraping collimators and loss monitors. Substantial non-gaussian tails and a dependence on machine parameters like chromaticity has been observed in the vertical plane.

We use tracking programs and started to included scattering processes. First results indicate that the far horizontal tails observed in LEP are mainly due to the Compton scattering of beam particles on thermal photons.

7 REFERENCES

[1] G. Arduini et al. LEP1 operation, 1989-1995. these proceedings.

[2] H. Burkhardt and R. Kleiss. Beam Lifetimes in LEP. In V. Suller and Ch. Petit-Jean-Genaz, editors, *Proceedings of the 4th European Particle Accelerator Conference*, volume II, page 1353 ff., 1994.

[3] R. Bailey et al. Operational Procedures to obtain high Beam-Beam Tune Shifts in LEP Operation. In *Proceedings of th Particle Accelerator Conference*, 1995. and CERN-SL-95-49 (OP).

[4] H. Burkhardt. What is the maximum current we can collide at 45 GeV. In J. Poole, editor, *Proceedings of the 5th Workshop on LEP Performance*, page 131 ff., 1995.

[5] S. Zholents. Experimental Programme. In J. Poole, editor, *Proceedings of the 2nd Workshop on LEP Performance*, page 387 ff., 1992.

[6] K. Cornelis et al. Commissioning of a Scintillator at the Aperture Collimators for the Study of Beam Tails. SL-MD Note 60, CERN, 1992.

[7] W. Bialowons, F. Ridoutt, and K. Wittenburg. Electron Beam Loss Monitors for HERA. In *Proceedings of the 4th European Particle Accelerator Conference*, 1994.

[8] H. Burkhardt et al. Scrapers and Tails. SL-MD Note 175, CERN, 1995.

[9] I. Reichel. RWTH Aachen (Germany) and CERN, work for a Ph.D. thesis on transverse beam profiles in LEP.

[10] H. Burkhardt and I. Reichel. Correction of the LEP beam loss monitors for known saturation effects. SL Note 96-26 (OP), CERN, March 1996.

[11] H. Burkhardt. Monte Carlo Simulation of Beam Particles and Thermal Photons. SL Note 93-73 (OP), CERN, July 1993.

[12] 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.

[13] S. Myers. Simulations of the beam-beam effect for e^+e^- storage rings. In *Nuclear Instruments and Methods 211*, pages 263–282. North-Holland Publishing Company, 1983.

[14] E. Keil. Nonlinear coherent effects between two strong bunched beams colliding in a storage ring. In *Nuclear Instruments and Methods 188*, pages 9–14. North-Holland Publishing Company, 1981.

[15] T. Chen, J. Irwin, and R. Siemann. Simulation of the Beam-Beam Lifetime for LEP. In V. Suller and Ch. Petit-Jean-Genaz, editors, *Proceedings of the 4th European Particle Accelerator Conference*, volume II, page 1356 ff., 1994.