LEP PERFORMANCE AT 91.5 GEV


Abstract
The 1997 LEP collider run was the first year of the LEP2 program devoted to stable high luminosity running. The good performance of the LEP superconducting RF system allowed to run at beam energies of 91.5 GeV. In addition to the usual optimisation procedures to minimise the vertical beam emittances, the horizontal beam sizes were reduced by increasing the horizontal damping partition number and reducing the betatron function at the interaction points. Vertical beam-beam tune shifts in excess of 0.05 were achieved with total beam currents of 5 mA. The total integrated luminosity of 73 pb⁻¹ is the highest ever recorded in a single year of LEP operation.

1 BEAM ENERGY AND RF
During 1997 LEP was operated routinely at 91.5 GeV. The choice of the energy was dictated by the available total RF voltage. The design gradient of 6 MV/m for the 224 superconducting Nb/Cu cavities was generally met. Taking into account those design fields and the gradients provided by the copper RF system, the total voltage that could be delivered was 2650 MV. In practice about 95% of the voltage, 2540 MV, was available for operation. This would allow for a trip of a high voltage power converter, which supplies 16 cavities, without losing the beams at 91.5 GeV. Such severe trips accounted for about 7% of all RF trips. The mean time between trips increased from about 50 to 70 minutes in the course of the run. 10% of the LEP fills were lost due to RF trips.

2 LEP PERFORMANCE IN 1997
To maximise the performance of LEP the bunch currents are first increased until the beam-beam limit is exceeded with 4 bunches per beam. Then the number of bunches is increased to 6 or 8 per beam as long as they are no limitations to the total beam currents.

In 1997 LEP ran with 4 bunches per beam and a total current around 5.5 mA, because the available cryogenics power prevented running with much higher total intensities. Significantly higher beam currents would have been required to reach equivalent performance with 6 or 8 bunches per beam, making life difficult for the RF and the vacuum systems.

Total beam currents of 5.4 mA, limited by synchro-betatron resonances, were typically accumulated at injection into 4 bunches per beam. In collisions the total current was usually 5.0 mA at the start of fill, the ramp transmission efficiency being 90%. Those currents were about 20% larger than in 1996 thanks to a reduction of the transverse impedance due to the replacement of copper RF cavities by superconducting cavities.

During 1997 LEP delivered a total integrated luminosity of 73.3 pb⁻¹ (Figure 1). 63.8 pb⁻¹ were produced at beam energies ranging from 90.5 to 92 GeV, with 92% of the luminosity delivered at 91.5 GeV. The best performance over 24 hours resulted in 1.9 pb⁻¹. Peak luminosities reached 5 \times 10^{31} \text{cm}^{-2}\text{s}^{-1} at the beginning of fills and beam-beam tune shifts \xi beyond 0.05 where recorded. 2.3 pb⁻¹ were delivered at 45 GeV for the LEP detector calibrations. A dedicated run at 65 and 68 GeV to check the existence of a signal observed in 1995 by one of the LEP experiments produced 7.3 pb⁻¹. LEP was colliding beams for physics during 44% of the allocated time. 7% of the scheduled time was also used for beam energy calibration. The down time was dominated by vacuum problems caused by the high levels of synchrotron radiation, by the RF and by the cryogenics systems. About 20% of the fills were lost due to equipment failures. The average turn-around time from a beam dump to the next collisions was 108 minutes.

For most of the year LEP was running with an optics having an arc phase advance per cell of 90° in the horizontal and 60° in the vertical plane (90/60). For the last 10 days...
a 102/90 optics yielding smaller horizontal emittances was tested in operation. The performance reached levels similar to the 90/60 optics and the integrated luminosity delivered with the 102/90 optics was 2.5 pb\(^{-1}\). This optics will be used for operation in 1998.

3 BEAM SIZE OPTIMISATION

In \(e^+e^-\) storage rings the dependence of the horizontal beam emittance \(\varepsilon_x\) on the beam energy \(E\) and on the horizontal damping partition number is

\[
\varepsilon_x \sim \frac{E^2}{J_x}
\]

for a given optics and phase advance in the arcs. The natural increase of \(\varepsilon_x\) with beam energy leads to higher backgrounds in the experiments and lower luminosities. To reduce the impact of the emittance increase, \(J_x\) was shifted from the usual value \(J_x = 1\) to \(J_x = 1.6\). This change was obtained with a +120 Hz change of the RF frequency. Since the change of damping partition number also increases the beam energy spread, a higher RF voltage is required for the same beam energy to guarantee a sufficient quantum lifetime. At LEP the top beam energy being limited by the available RF voltage, the beam energy must be reduced by about 0.4 GeV with respect to \(J_x = 1\) to guarantee a sufficiently large quantum lifetime of the beams.

A further reduction of the horizontal beam size was obtained by squeezing the horizontal betatron function at the interaction points \(\beta_x^*\) from 2.0 to 1.5 m. Figure 2 shows the horizontal beam sizes at the interaction points for \(\beta_x^*\) of 2.0 and 1.5 m and \(J_x = 1.6\). Backgrounds in the experiments did not increase significantly.

The \(J_x\) and \(\beta_x^*\) changes resulted in an increase of the luminosity of about 1.45 with respect to 1996. The natural increase of \(\varepsilon_x\) between 86 and 91.5 GeV leads at the same time to a 6% luminosity reduction. The overall improvement of roughly a factor 2.3 in luminosity production rate compared to 1996 seen in Figure 1 is also due to 20% higher average bunch currents (factor 1.5) and to a faster turnaround time.

To ensure small vertical beam sizes in collision the coupling between the horizontal and vertical planes is carefully adjusted with skew quadrupoles. The amount of coupling is measured at LEP by the closest tune approach [1]. It is corrected during the LEP startup period down to the measurement resolution.

The performance is steadily improved during the run with the help of “Golden Orbits” [1]. Such orbits give reproducible high performance with optimum vertical emittance \(\varepsilon_y\) and are obtained by trial and error using various orbit correction algorithms. In 1997 the smallest emittances of \(\varepsilon_y = 0.25\) nm corresponded to vertical beam sizes of 3.5 \(\mu\)m at the interaction points. When the coupling between the two planes is well corrected, \(\varepsilon_y\) seems to be limited by the residual vertical dispersion and beam-beam effects. This minimum of \(\varepsilon_y\) varies from one running period to the next at energies above 80 GeV. The smallest value of \(\varepsilon_y = 0.15\) nm was measured in 1996.

Figure 3 shows the correlation between the vertical beam-beam tune shift \(\xi_y\) and the bunch currents for all LEP fills with \(\beta_x^* = 1.5\) m. Although there is a slight levelling of at high currents, there is no strong evidence that the beam-beam limit has already been reached.

Single beam lifetimes at high energy are, for good vac-
40 to 55 GeV using Nuclear Magnetic Resonances probes and flux measurement loops. The accuracy of this procedure depends on the highest energy at which resonant depolarization is possible as well as on the lever arm of calibrated energies. Between 1996 and 1997 the lever arm was increased from 5 to 14 GeV and the highest calibrated energy was increased from 50 to 55 GeV [5].

6 CONCLUSION

Higher bunch currents and smaller horizontal beam sizes made it possible to boost the LEP performance by more than a factor two between 1996 and 1997. Record beam-beam tune shifts over 0.05 were observed. A further reduction of the transverse impedance in 1998 and the use of an optics with smaller horizontal emittance could further improve the performance in the coming years.

7 REFERENCES