LEP Performance, Polarization and Energy Calibration

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Abstract

The LEP integrated luminosity has increased by a factor of two between 1990 and 1991. This is the result of an improvement of the magnetic optics which finds a better compromise between single particle dynamics and the beam-beam effect. Part of this improvement is expected as well from a tighter control of the optical imperfections, especially the position of the insertion quadrupoles. The radiation loss and background to the detectors were kept low in spite of a reduction of the size of the experimental vacuum chamber. The availability of LEP for physics was 45 %, with a down-time of the main ring of 12 %. The limited reproducibility of the main ring optics and the combined fault rates of the sequence of accelerators are the main cause for the loss in efficiency. The analysis of the beam dynamics limitations show that LEP has still a significant potential for performance improvement. In 1991, the polarized beam which was first produced at the end of 1990 could be reproduced several times. A method of artificial depolarization was developed, allowing an accurate measurement of the beam energy. In 1992, the LEP magnetic optics will be drastically modified to prepare the exploitation of a pretzel scheme, with a potential of doubling the luminosity, and the energy increase to 90 GeV.

1 LEP Performance

1.1 Luminosity and background

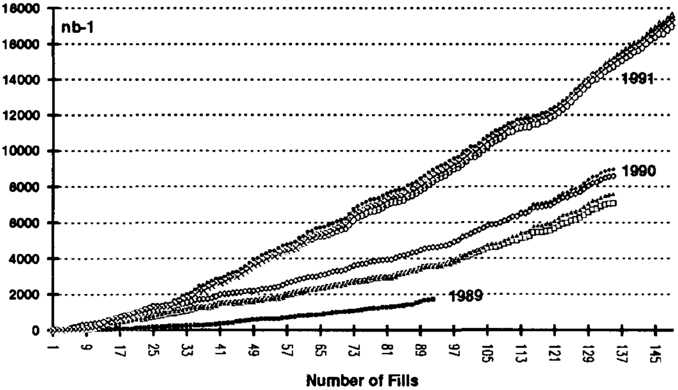

Figure 1: Integrated luminosity in 1989,1990 and 1991

The integrated luminosity accumulated in 1991 is 1.9 times higher than in 1990 over the same period (figure 1) [1] and identical at all interaction points. In spite of the reduction from 156 to 106 mm of the inner diameter of the experimental vacuum chamber, the photon background to the detectors did not increase as expected. The radiation losses during accumulation and acceleration were kept low by a strict policy of collimation.

1.2 Efficiency

The relative coast time which measures the efficiency for physics was comparable to

Table 1: Statistics of LEP operation in 1991

State	System	Fraction of the time
Coast		44 %
Filling		20 %
Down		36 %
	LEP	12 %
	Injectors	14 %
	Delphi vac. ch.	6.5 %
	Access	3.5 %

that achieved in 1990 (table 1). The main causes for loss of efficiency are: the non-reproducibility of the magnetic optics and beam dynamics, weaknesses in the control system and procedures, and the number of subsystems in series, which limit the ultimate efficiency to some 70 %. Many of these points are being improved.

1.3 Improvements in 1991

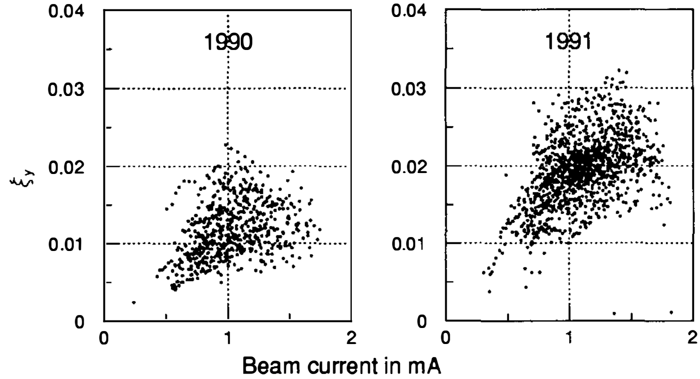

Figure 2: Beam-beam parameter in 1990 and 1991

In 1991, the magnetic optics was modified in the non-experimental interaction points to allow a change of the integer part of the betatron tunes. When commissioning LEP, the latter were 70 and 78, chosen to provide the highest luminosity and the lowest sensitivity to optics imperfections; they had to be changed to 71/77 due to the proximity of a coupling resonance excited 100 times more than expected by a nickel layer on the vacuum chamber. After a year of operation, it became clear that the beam-beam limit was rather low and could be explained either by a systematic beam-beam resonance close to the working point or by optics imperfections [2]. The machine being better known, the tunes were changed to 70/76, always keeping a difference of 6, but now with a vertical tune being a multiple of the LEP focusing symmetry. This tune amplifies the effect of optics imperfections but avoids the systematic beam-beam resonance present on the 71/77 optics.. Due to this sensitivity, the LEP operation was faced with various problems which could be cured gradually (β_y^* errors, non closure of separators bumps, ...). Nevertheless the luminosity increased as expected (figure 2)[3]. A side effect of the even parity of the betatron tunes is that the effect of optics imperfections is similar in the four interaction points, i.e. the luminosity was the same at all points (figure 2).

The SPS electron beam intensity and thus the LEP injection rate were doubled in 1991. The synchro-betatron resonances are then crossed more rapidly, which has been seen to facilitate accumulation.

1.4 Performance limitations

The main LEP limitation is the beam blow-up caused by the beam-beam effect which appears as a linear decay of the luminosity with time and a constant beam-beam parameter ξ [3]. The latter varies from run to run (figure 2), showing that some important parameters

Table 2: Main limitations to LEP Performance

Limitation on ...	*Source(s)*	*Average/peak bunch current (μA)*
luminosity	**Beam-beam effect**	350/450
background	Reproducibility Specified tolerances	
Turnaround: Injection Accumulation	 Reproducibility Procedures & diag. long-range beam-beam synchro-betatron res. Head-tail oscillations Transverse Mode Coupling Procedures & diag.	435/537
ramp	Reproducibility Procedures & diag.	350/520

are not controlled. The effect of the optics imperfections (betatron phase advance between collisions, dispersion at the interaction points) are suspected, but are difficult to measure. New methods are being investigated.

The second limit appears as a long range beam-beam effect, which drives transverse oscillations modes reducing the space in the tune diagram to accumulate current [3]. To reduce this effect, the beam separation and the focusing at the interaction point were increased with mixed success.

The other mechanisms are related to the collective behaviour of the bunches [4]. Although they presently do not limit the beam current, they contribute to the turn-around by making accumulation difficult or lengthy. They are well understood individually; the difficulty lies in disentangling them and minimizing their consequences.

2 Polarization and Energy Calibration

The electron beam coasting in LEP tends to polarize itself in the direction of the guide field up to a maximum of 92.3 %. A competing mechanism is the quantum noise created by the non spin-flip photon emissions and exciting the orbital motion. In presence of optics imperfections, this causes depolarization scaling with the square of the energy. For example, the same optical imperfections which would result in an equilibrium polarization of 20 % in PETRA would give 2 % in LEP. Other difficulties are the long rise time of the polarization (300 minutes at 46.5 GeV) and the large beam energy spread (128 MeV at 2σ) giving rise to higher-order spin resonances.

2.1 Polarization level

Apart from one experiment, polarization was always observed at an average value of 10 % (table 3)[5]. The optics was close to the injection optics, with the experimental solenoids switched off. Due to the emphasis on energy calibration, no attempts at harmonic spin matching was done to compensate spin resonances.

Table 3: Measured polarization levels

Experiment	1990	1991-1	-2	-3	-4	-5	-6	-7	-8
Pol. level %	9	11	9	-	5	8	20	10	8

2.2 Artificial depolarization

The principle of artificial RF depolarization is to perturb the spin precession by applying a variable magnetic field. When its frequency resonates with the main spin precession which is energy dependent, the perturbations add up and depolarization occurs. The resonant frequency yields the energy of the beam with an ambiguity which is easy to resolve. At the high energy of LEP, it is necessary to excite the spin resonance with a transverse magnetic field rather than a solenoidal field which is 100 times less efficient. The method becomes thus more delicate, as transverse fields excite as well betatron resonances which may depolarize the beam by a different mechanism. We found at LEP that the decay of the horizontal component of the spin vector is much slower than estimated so far, creating correlations between spin resonance crossings. We thus adopted a strategy of a unique very slow resonance crossing which was made possible by the availability of the strong LEP transverse feedback kickers (4 Gm).

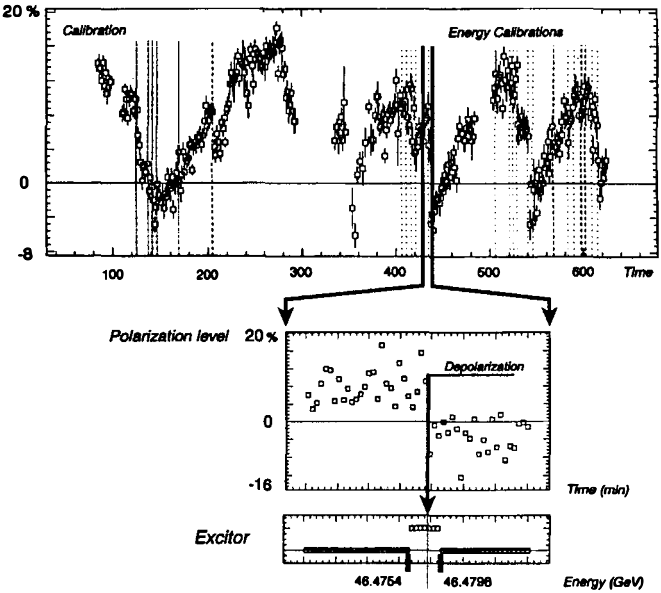

Figure 3: Polarization and RF depolarizations of the LEP beam

Depending on the purity of the depolarization event (figure 3), the accuracy may range from ± 2 MeV to ± 300 KeV peak in 46 GeV [5]. At this level of precision (less than 5 % of the rms beam energy spread), subtle effects may create systematic errors. We have considered so far the effect of betatron resonances, synchrotron modulation and certain non-linear optical effects without finding limitations.

2.3 Results and interpretation

The energies measured so far show a variability significantly larger than the measurement accuracy (table 4). The most convincing correlation arises between the strength of the

Table 4: Energy calibration data in 1991, expressed as the difference between the polarization and magnetic measurements

Date	ΔE MeV
16.09.91	-37.1 ± 1.2
02.10.91	-32.5 ± 1.2
26.10.91	-31.4 ± 1.2
11.11.91 2am	-37.5 ± 1.6
11.11.91 7am	-33.6 ± 1.2

tidal force on the earth which may change the LEP circumference by some 3 10^{-8} and the measured energy [6]. This hypothesis will require delicate checks.

In the hunt of subtle systematic errors in the energy calibration, it was realized that the beam energy in the interaction points may vary by as much as 8 MeV due to a peculiarity of the LEP double-frequency RF system. Other effects have been evaluated to be significantly lower than 1 MeV.

3 Conclusion

The year 1991 was very positive, with a significant improvement in performance and the development of the polarization programme which now allows a measurement of the Z mass and width to a very high accuracy.

In year 1992, a profound modification of the LEP optics will allow the operation of the pretzel scheme, with a potential of doubling the luminosity, and the preparation of the energy upgrade. When the new optics is well behaved, the efforts will go towards making the polarization compatible with the physics optics.

References

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