LEP Operation in 1992 with a 90^{o} optics

R. Bailey, T. Bohl, F. Bordry, H. Burkhardt, K. Cornelis, P. Collier, B. Desforges, A. Faugier, V. Hatton, M. Jonker, M. Lamont, J. Miles, G. de Rijk and H. Schmickler

CERN
CH-1211 Geneva 23, Switzerland

Abstract

The optics for physics operation in LEP was changed from 60^{o} to 90^{o} at the start of 1992 with a view to improved Z^{0} production, preparation for future operation at higher energies and the use of the same optics in machine developments. The developments included running LEP with twice the number of bunches and using resonant depolarisation for energy calibration. Perturbation to steady operation was felt at the start of the year but was soon overcome as the benefits of smaller emittances were realised. The peak luminosity increased to 1.15 10^{31} and the luminosity lifetime improved. New operational software halved the time taken between dumping one coast and the start of data taking on the next. The 8+8 bunch operation was introduced as routine operation for the last month. Overall, there was an increase in integrated luminosity from 17.6 inverse picobarns per experiment in 1991 to 28.6 in 1992. Along with improvements in detector efficiency, almost 3 million hadronic Z^{0}s were recorded by the four experiments, an increase from 1.27 million in 1991.

1. Introduction

LEP was operated for the whole of 1992 with a phase advance per cell of 90^{o} compared to 60^{o} in previous years. This optics was designed to produce low emittance beams for physics while also being suitable for operation with Pretzels, for polarisation studies and in the longer term for LEP2. After initial difficulties with the commissioning, performances easily surpassed those of previous years.

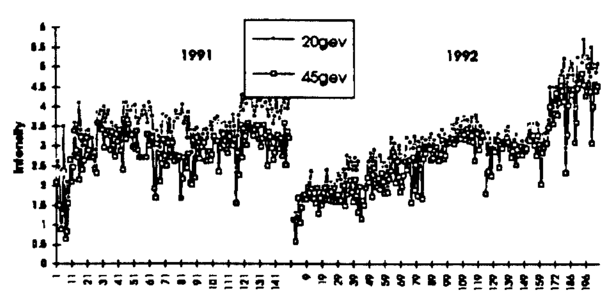
The whole of the year's running was at the Z^{0} peak, mostly with 4 bunches in each beam. Towards the end of the year, however, and following a substantial program of machine development throughout the year, the machine was operated with 8 bunches per beam circulating on Pretzel orbits [1].

2. Filling and preparation for physics

The procedure for filling LEP during 1992 was much the same as in previous years [2]. Bunches of 20 GeV positrons and electrons supplied by the SPS are injected into LEP during a 4.8s slot in the 14.4s SPS supercycle. Accumulation is achieved by repetitive injection of this kind, typically over about 30 minutes. Accumulation rates were similar to 1991, but the total beam currents achieved during 1992 were somewhat less than in the previous year (See Table 1 for details). This comes from the fact the LEP intensity is presently limited not by single beam phenomena, but rather by beam-beam excitation of transverse instabilities. With lower emittance beams, the threshold for these effects is lower.

In previous years two different ways of getting from the 20 GeV machine into physics conditions have been used. During the early years of operation, beams were first ramped in energy and then squeezed in beta*y at the experimental interaction points. Towards the end of 1991 running, these two actions were combined, resulting in a simultaneous energy ramp and beta* squeeze. This meant that at the end of the energy ramp, which presently takes around 7 minutes, the machine was already set to the physics optics, and a considerable amount of time was saved in this way. In 1992, with the low emittance optics, the combined ramp and squeeze was never mastered and it was necessary to fall back to separating these two functions. This did not in fact incur much overhead, since the machine was being driven by new applications software which made it possible to run through a separated ramp and squeeze in just 12 minutes [3]. Indeed, over the whole year, the turnaround time between physics runs was almost halved compared to the previous year. Furthermore the amount of beam lost during ramping the machine was significantly less than in previous years (Fig 1). This was due partly to a slightly smaller 20 GeV intensity to start with, but also the new software ensured the integrity of the ramp settings much more than in previous years.

Figure 1 - Intensities at 20 and 45 GeV



0-7803-1203-1/93$03.00 © 1993 IEEE

Table 1 - Comparison between the 4 years of LEP running

		1989		1990		1991		1992	
Total hours scheduled	Hrs.		3107		3433		4002		4883
Hours scheduled for commissioning	"		1284		0		0		501
Hours scheduled for setting-up	"		48		240		243		509
Hours scheduled for MD	"		454		689		997		935
Hours scheduled for physics	"		1321		2504		2762		3439
Hours of beam in coast	"		469		1048		1242		1742
Efficiency	%		35		43		45		51
		peak	*avg.*	*peak*	*avg.*	*peak*	*avg.*	*peak*	*avg.*
Total current accumulated 20Gev(4+4)	mA.	2.85	2.2	4.2	3.1	4.3	3.5	4.5	3.2
Total current accumulated 20Gev(8+8)	mA							5.7	4.7
Current in collisions 45Gev(4+4)	mA.	2.64	1.66	3.6	2.5	3.7	2.8	4	2.4
Current in collisions 45Gev(8+8)	mA							5	4.2
Initial luminosity cm-2 s-1 *	10^30	4.25	1.59	11	5.1	10		11	
Integrated luminosity	pb-1		1.74		12.1		18.9		28.6
Beta at the experiments (v)	cm	7	7	4.3	7 & 5	4.3	7.5 & 5		5&7
Filling time	h:mn	0:50	7:35	1:20	6:57	01:20	03:07	00:50	02:12
Coast duration	h:mn	12:45	5:00	22:35	7:30	27:00	08:00	26:30	08:35
Total number of coasts			97		143		154		199
Percentage of coasts lost	%		35		33		36		36

3. Tuning during physics

While running with low emittance beams in collision is of course good for luminosity, it caused problems due to the large beam-beam effects induced. These effects were so large that it proved impossible to maintain good lifetimes after bringing low emittance beams into collision when the total current in the machine exceeded 2 mA. It proved necessary to blow up the transverse emittance with wigglers before bringing the beams into collision. With this mechanism in use the currents in physics were slowly increased throughout the year, eventually reaching levels comparable with previous years. The big advantage during 1992, however, was that throughout the physics coast it was possible to gradually reduce the wigglers to reduce the beam size as the intensity fell, thereby maintaining luminosity levels. While this procedure proved very productive, it meant that machine conditions were often changed, and the operators had to optimise parameters frequently through the run.

Instantaneous luminosity levels achieved in this way were much the same as in previous years, with best performances in the region of 10^{31} cm^{-2} s^{-1}. However by maintaining luminosity levels for longer through the run, the integrated daily and weekly rates were higher. Figure 2 shows the evolution of the integrated luminosity throughout the year compared to 1990 and 1991. Figure 3 compares data from the last 2 years in terms of the number of Z^0 detected by the four experiments. Here the increase is more pronounced due to increased efficiency in the detectors and to the fact that all the 1992 running was on the peak while in 1991 energy scanning was performed.

Figure 2 - Integrated luminosities

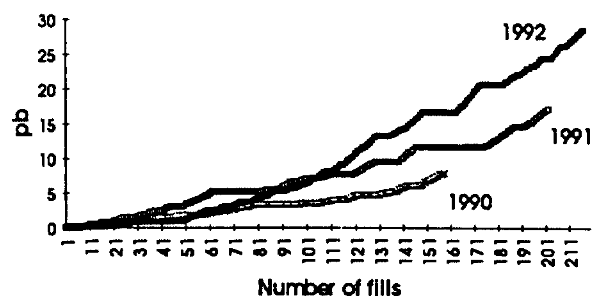
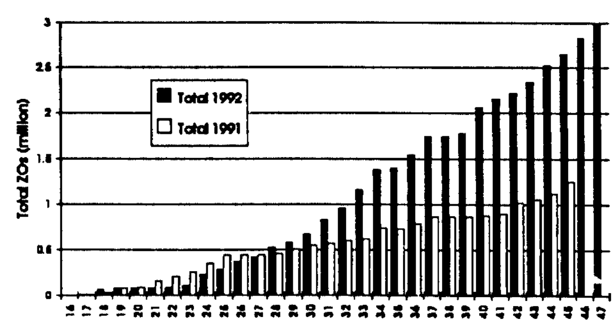


Figure 3 - Z0 Production



4. 8 bunch operation

For the previous years' running and for most of 1992, LEP has been operated with 4 bunches per beam. Unwanted beam collisions, of which there are 8 during filling and preparation for physics, and 4 during physics, are avoided by a local vertical separation scheme [4]. In order to go to 8 bunches per beam a horizontal Pretzel scheme, developed during 1991 and 1992, was introduced into routine operations for the last four weeks of running [1].

Filling 8 bunches per beam in LEP was achieved with no change to the injectors. Instead the LEP RF synchronisation was flipped back and forth on successive SPS supercycles, filling alternatively normal and 'Pretzel' bunches. Towards the end of the year this was achieved in an automatic way.

The maximum bunch intensities achieved during Pretzel operation were about 70% of those achieved during normal four bunch running. With 8 bunches per beam there are extra long-range encounters in the middle of the arcs, which further limit the accumulated current. The mechanism appears to be the same as that limiting the current in the four bunch case, but at a lower threshold.

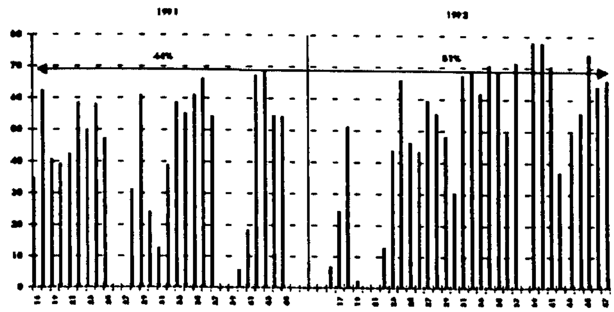
The overall operational efficiency was little affected by 8 bunch operation. Even with the filling scheme described above, accumulation times were only slightly higher than with 4 bunches per beam. Ramp and squeeze efficiencies were also comparable to those achieved with four bunch running. However a further factor of 70% was observed in the luminosities achieved for a given bunch current. This probably came from a combination of beam blow-up and a residual horizontal miscrossing at the experimental interaction points.

These two factors of 70% combined to cancel out the gains coming from having twice the number of bunches in the machine. Nevertheless the break-even point was reached early in the 8 bunch operation, and as more experience was gained throughout the few weeks of running, peak luminosities were seen to gradually increase. The highest luminosity ever seen in LEP was 1.2 10^{31} cm^{-2} s^{-1}, achieved during 8 bunch operation.

5. Efficiency during operations

The LEP efficiency is defined as the number of hours with beams in coast divided by the number of hours scheduled for physics. Since LEP has to be filled, ramped squeezed and prepared before physics can start, this figure can never reach 100%. The efficiency has been slowly increasing since the start of LEP (see Table 1), and in 1992 was above 50% for the first time. During later running this figure was higher, even during the 8 bunch operation at the end of the year (Figure 4).

Figure 4 - Operational efficiency



The overall efficiency of LEP operation benefited from running with a single optics through the year. Transition from physics to machine study periods and back were more efficient than in previous years. In particular the development of the Pretzel operation on the same optics used for physics was particularly beneficial.

The percentage of coasts lost, rather than intentionally killed, was 36%, a value very similar to that of the three previous years (see Table 1).

5. Summary

The average integrated luminosity measured by the four LEP experiments in 1992 was 28.6 inverse picobarns. The peak luminosity observed in any of the 199 fills made was 1.2 10^{31} cm^{-2} s^{-1}, achieved during Pretzel running. All running was at the peak, which together with an improved efficiency of the experiments resulted in a total of 3.0 million hadronic Z^0s recorded in all experiments.

6. References

[1] Commissioning and operation of the LEP Pretzel scheme
J. M. Jowett et al., these proceedings

[2] Three years operational experience with LEP
V. Hatton et al., paper presented at the 1992 European Particle Accelerator Conference, Berlin

[3] The impact of new accelerator control software on LEP performance
R. Bailey et al., these proceedings

[4] Commissioning and operating experience with the electrostatic beam separation system of LEP
W. Kalbreier et al, paper presented at the 1990 European Particle Accelerator Conference, Nice