First Two Years Operational Experience with LEP

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Abstract

On July 14, 1989 a beam of positrons was injected into LEP from the SPS and completed the first full turn. One month later all 4 experiments, ALEPH, DELPHI, OPAL and L3 detected their first Z^0 particles.

From September to December 1989, the machine was operated in a mixed mode of machine studies and operation for physics. At the end of this period a total of over 1.7 inverse picobarns of integrated luminosity had been recorded per experiment, resulting in a total of more than 70,000 Z^0s detected.

At the request of the physicists, the energy of each fill was varied, half the number of fills were at the Z^0s peak, i.e. a centre-of-mass energy of 91.25 GeV, the rest at ± 3, ± 2, ± 1 GeV around the peak energy.

During 1990, LEP was operated in the same way as in 1989. From March to July 1990, 12.1 inverse picobarns and three quarters of a million Z^0s were produced.

Physics fills of 6 hours duration in 1989 were increased to 10-12 hours in 1990 as the lifetimes of the beams increased with the steadily improved vacuum in the ring.

This paper summarizes the experience over the first two years of LEP operation giving typical and peak performance figures.

I. The Filling Process

The first part of the SPS supercycle is dedicated to injection, acceleration and extraction of protons from 14 to 450 GeV.

Four bunches of positrons at 3.5 GeV are then injected and accelerated to 20 GeV before being ejected and transferred to LEP. Four more bunches of positrons follow 1.2 seconds later followed by two cycles of four electron bunches. Intensities of about 8 x 10^9 particles per bunch are typical. In special machine-study sessions a single bunch current of 0.75 mA (approximately 4 x 10^{11} particles) has been accumulated, with a total of 2.8 mA in the four bunches. The design intensity is 0.75 mA in each of the four electron and positron bunches.

Under optimum conditions the leptons are injected into LEP and accumulated at a rate of 0.3 mA per minute. The average total intensity of electrons and positrons accumulated at 20 GeV in 1989 as 2.2 mA; there was little increase from September to December, 1989. In 1990, after optimizing the length of the bunch coming from the injectors from 2.5 to 3.0 ns, and a change of working point from Qh = 71.375, Qv = 77.290 to Qh = 71.280, Qv = 77.190, there was a steady increase in accumulated current to an average overall fill of 3.1 mA, with a maximum of 4.2 mA.

Beam is accumulated at 20 GeV in the machine with low beta insertions, ß* of 21 cm, provided by the superconducting quadrupoles in those regions in the four experimental points.

Ramping the beam to physics energies from 20 to 45.625 GeV is reached in 7 minutes at present although this can be reduced to less than 1 minute if required.

Squeezing of the beams at collision energies in the four interaction regions is applied after correction of tunes and closed orbit. The squeeze in the vertical plane from 21 cm to 7 or 5 cm takes about 2 minutes; this is followed by further tune and orbit corrections.

II. Machine Performance for Physics

With averages of 3.5 mA total beam accumulated at 20 GeV, 3.0 mA are typically seen in the experiments after the ramp and squeezing process at 45 GeV with modest background levels. Steady reproducible operation for the four experiments has been possible with these levels of intensity. Peak and mean performance figures for 1989 and 1990 are given in Table 1.

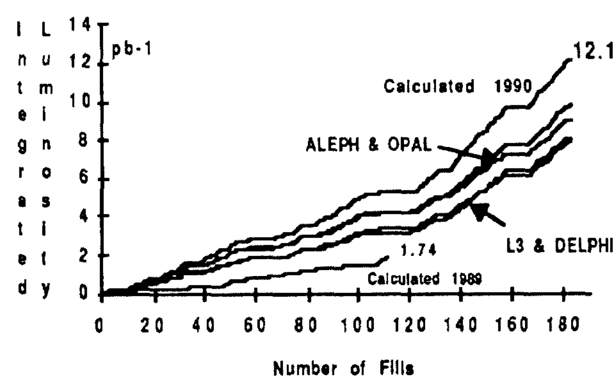

Figure 1. Integrated luminosity for 1989 and 1990.

The integrated luminosities for 1989 and 1990 are plotted in Figure 1 together with the integrated luminosities, for 1990, measured by the four experiments. At currents in excess of 3 mA at peak energies, there is an appreciable beam-beam effect which leads to increased beam size and corresponding reduction in luminosity seen by the experiments compared to that expected from scaling with intensity.

Attempts to run for physics at vertical beta* lower than 7 cm in 1989 were stopped due to non-reproducibility of results; in some experiments, there was no measurable improvement in the luminosity at the lower values. Operation at 4.3 cm was much more critical than at 7 cm. In 1990 good reproducible operating conditions were achieved with a ß* of 5 cm.

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In common with the experiences reported from other electron machines [1], good vertical orbit control is essential to achieve satisfactory accumulation at the injection energy and high luminosities at top energy. Furthermore, a well-corrected vertical orbit in the RF straights helps to reduce the risk of synchro-betatron resonances. As is well known [2], the effect of coupling together with the influence of the vertical closed orbit on residual vertical dispersion, have a strong impact on vertical emittance. The notion of "Golden Orbits", which provide short-term reference points for good operation, was invoked in 1990 with some success. Empirical application of symmetric and asymmetric vertical closed orbit bumps around the even interaction points (thereby including the superconducting insertion quads, beta ~ 400 m) was also used operationally with success. These bumps modified the dispersion and also had the effect of improving the background conditions for the physics experiments.

Since the beginning of 1990 continuous measurements of the tunes during critical phases of machine operation like energy ramping or beta squeezing are possible. This is either done in the FFT mode of the Q-measurement system or in PLL mode. On the first case the tunes are derived from the peaks of the spectral distribution of the beam movement or in the second case, by reading the frequency of the beam exciter, which by means of a phase lock condition maintains steady beam oscillations at the resonance of the beams.

These measurements were successfully used to correct the current variations during energy ramping to maintain the tunes constant within $\Delta q \leq 0.02$.

A further improvement in tune stability was the contruction of a closed loop digital tune digital tune regulator, which based on the continuous tune measurements computer correction signals for the main quadrupole PCs and maintained the tunes constant within $\Delta q \leq 0.005$.

The different luminosities seen by the four experiments were extensively studied. In the last month of operation in 1990, optimization of the currents in the low-beta insertion superconducting quadrupoles resulted in an improved uniformity and an overall increase for given intensities. One source of the difference was traced to a misalignment of the quadrupoles in the cryostat.

III. INTERRUPTIONS TO NORMAL OPERATION

An average of 36% of the scheduled time for physics operation was spent data taking in 1989 and 43% in 1990.

In 1989 and 1990, 35% and 33% respectively of all fills were lost due to equipment faults. A number of these occurred when a power converter tripped off due to cooling problems, or the mains voltage dipped. Concerning the RF system, the largest such system in the world, trips in one or more of the RF units was a feature of LEP operation in 1990.

During the period of commissioning of the many LEP systems efficiency was reduced in 1989 by the second type, as is usual with a new and complex machine. Improved understanding of the operation and faster recovery from equipment failures resulted in shorter turn-around times in 1990.

Table 1
LEP performance during physics operations in 1989 and 1990

		1989		1990		Design
		Best	Average	Best	Average	
Total current accumulated 20 GeV	mA	2.85	2.20	4.20	3.10	6
Beta at the experiments (V)	cm	7	7	4.30	7 and 5	7
Current in collisions 45 GeV	mA	2.64	1.66	3.60	2.50	6
Calculated initial luminosity	10^{30}	4.25	1.59	11.00	5.10	16
Calculated integrated luminosity	pb^{-1}		1.74		12.10	
Filling time	h:min	0:50	7:35	1:20	6:57	
Coast duration	h:min	12:45	5:00	22:35	7:30	
Total coast time/scheduled	%		36		43	
Total number of coasts			97		143	
Percentage of coasts lost	%		35		33	

pb^{-1} = Inverse picobarns. Calculation based on intensities, emittance.

Due to the high degree of computerization, software problems and inefficiencies caused significant delays between coasts in 1989. There has been considerable improvement in 1990 but much has still to be done.

All CERN machines are affected by critical days, i.e, days during which the electricity supply company, under the contract terms, can request the shedding of load for a period of 18 hours per day, for 22 days spread randomly over the 5 months from November to March. Six days of operation were lost in 1989 and five in 1990. Thunderstorms in the region result in interruptions due to voltage dips on the 50 km overhead 400 kV line from the power station to CERN.

The injector chain contributed little to the down time although vacuum leaks in the RF cavities in both the SPS and PS were a source of concern; the leaks were on the damping loop bellows which took the cavity off-tune during the passage of the high intensity protons. This was less of a problem in 1990.

Analysis of seven weeks of LEP fills in 1990 is shown in Table 2. The times for filling, ramping and squeezing for 60 fills are indicated compared to the shortest turn-around time so far recorded in 1990, fill number 235. Short-term interruptions randomly spread over all the LEP systems and non-reproducible accumulation conditions resulted in a doubling in the filling time. Fill times of about one hour are expected in 1991.

IV. JOINT LEP AND SPS OPERATIONS

A decision was taken early in the LEP project by the LEP management board that LEP should be operated from the SPS control building by the Group responsible for SPS operations. Combined operations of SPS and LEP has proved very successful.

During the commissioning phase the Operations Group worked with the equipment specialists and machine physicists, and by September 1989 the Group was in full operation control for physics running and contributed to the machine studies.

While the commissioning of LEP was being done, the SPS continued a full programme of fixed target proton physics, operated from the same building but from a room separate from LEP operations. In 1990, during the yearly two months maintenance stop, the SPS control room was modified and LEP operation consoles installed; the operation of the two machines is now successfully and efficiently done from the same room by a crew of four. There has been no measurable reduction in the efficiency of operation of the SPS during operation of LEP.

The primary services for LEP operation were also supervised from the SPS-LEP operations building during this period. These services include electricity, water, ventilation, cryogenics, vacuum, controls, radiation surveillance, fire alarms, and others. This function has been incorporated in the CERN-wide primary services supervision from the start of 1991.

V. ACKNOWLEDGEMENTS

The operation of the LEP machine demands the close collaboration between the operation teams, the equipment groups, the machine physicists and the experimental physicists for whom the machines run. The success of the operation of LEP reflects the success of these close collaborations and those with the engineers and physicists of the CPS and SPS complexes.

The authors would like to thank all the members of the Operation Groups, both CPS, SPS, and LEP for their support in this venture.

VI. REFERENCES

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Table 2
Analysis of seven weeks of LEP fills in 1990

	Down Time	Recovery	Accumulation	Ramp	Squeeze	Total fill	Physics	Total Cycle
Average	1:31	0:31	2:11	0:28	0:27	5:09	7:52	13:01
r.m.s.	2:18	0:45	1:55	0:14	0:18	3:28	5:04	6:12
Minimum	0:00	0:00	0:30	0:05	0:07	1:20	0:12	-
Maximum	10:00	4:10	11:15	1:10	1:40	16:50	22:35	34:00
Shortest fill time	0:30	0:00	0:30	0:05	0:15	1:20	9:02	10:22

All times in hours:minutes