7.6 Precise Energy Measurement: Heed the Moon

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In LEP the circumference, C, was determined by the orbit passing through the centre of all the quadrupoles, but the effective orbit length of the ultra-relativistic circulating beam was determined by the frequency of the RF system, which fixed the revolution frequency. If C changed by ΔC say, with the frequency kept constant the beam would move transversely in the magnets. This shift would move the beams off centre in the quadrupoles entailing a change in energy $\Delta E/E = \alpha_c^{-1}\,\Delta C/C$ where α_c is a beam parameter known as the momentum compaction factor. This latter factor was between 1.5×10^{-4} and 4×10^{-4} for LEP, so the energy calibration of the machine was extremely sensitive to geological motion caused for example by tides and variations in the water table which change C [43].

Tides are caused by the variation of the gravitational attraction of celestial bodies, principally the sun and the moon. The tidal forces produce local stretching in the horizontal plane and resulted in a peak-to-peak variation in the circumference of the machine of up to 1 mm. Following these calculations an experiment was performed during a period of full moon, the result of which is shown in Fig. 7.14. Thereafter the information generally available on the tides was put into a model that was used to correct for these effects in the determination of the true energy of the accelerator.

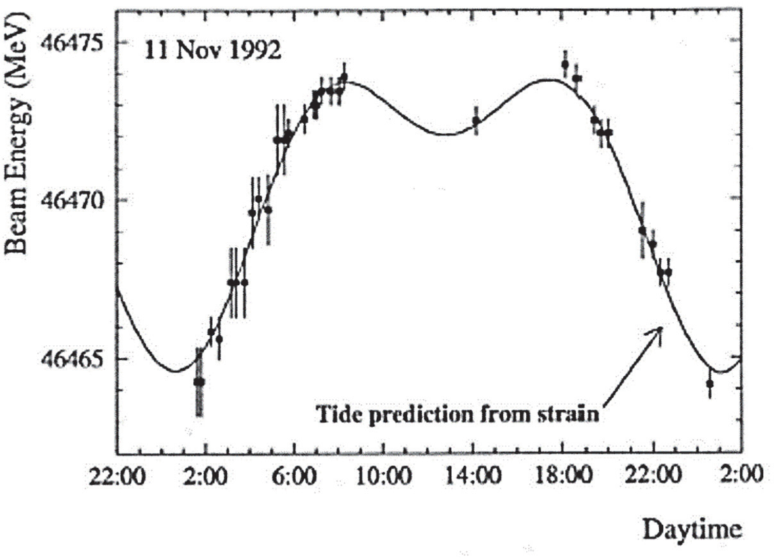

Fig. 7.14. Variation in the energy of LEP beams during a day of full moon. One can see the excellent agreement with the change in energy predicted by the calculation of horizontal strain due to the tides.

In addition to the daily and monthly tidal movements, LEP was also affected by long-term changes in circumference. The movement was observed by monitoring the radial movement of the beam relative to the quadrupoles using the beam position monitors during the annual period of operation of the accelerator for physics. Fluctuations seen during a typical period from May to November are shown in Fig. 7.15, displaying changes of up to 2 mm, a profile found to be very similar from year to year. The diameter tended to be larger during the summer months, and some of the changes were clearly correlated with rainfall. This monitoring of seasonal fluctuations was quite important for the experiments, as the resulting variation in energy was significant, being up to $\Delta E/E = 5 \times 10^{-4}$. Although this did not require the development of new equipment, it illustrates the skill of the operations team in understanding the machine performance in the utmost detail and led to a factor 10 improvement in the determination of the Z mass.

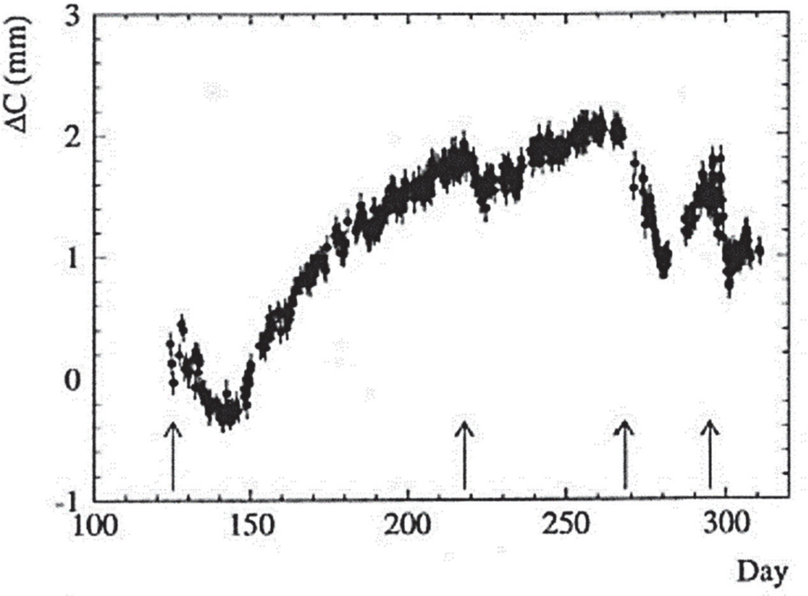

Fig. 7.15. Change of LEP circumference in 1996. A total drift of 2 mm was observed. It gradually increased during the summer, with rapid movements following heavy rain (indicated with arrows).