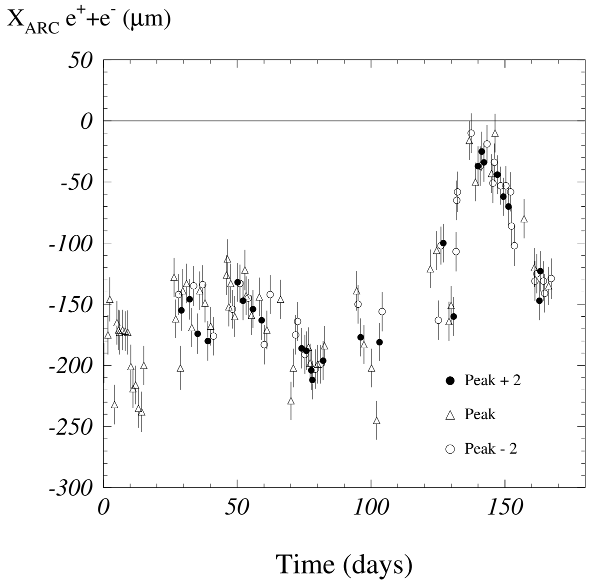

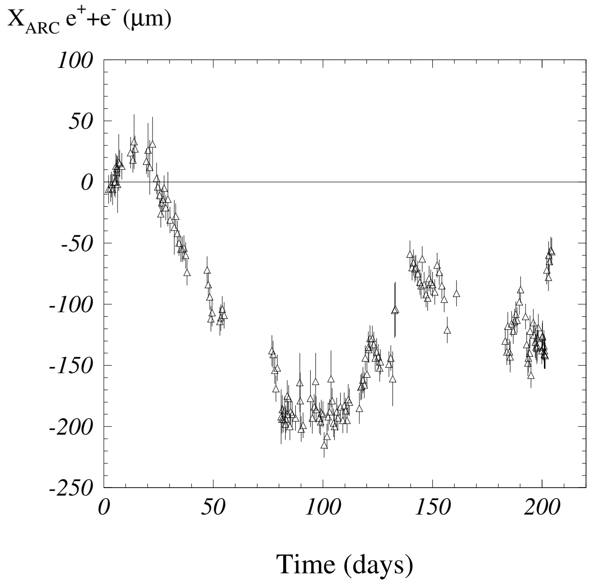

Figure 1: Evolution of the average horizontal beam position in the LEP arcs (X_{ARC}) in 1993 (left) and 1995 (right) after correction of the tides. The time scales start on June 1^{st} 1993 and May 1^{st} 1995. The structure around day 150 in 1993 is mainly due to an increase in the hydrostatic pressure in the rocks surrounding LEP after heavy rainfall. The step in the early part of 1995 is related to the annual increase of the water level in the Lake Leman in the late spring. The structures in the later part of 1995 are correlated with periods of rainfall.

Although the LEP dipoles account for more than 99.9% of the bending field seen by the beams, a small but non negligible fraction of the total field can also be provided by the quadrupoles. When a particle is going off-center through a quadrupole, it sees a magnetic field proportional to the distance to the center, leading to a relation between the average horizontal beam position and the beam energy. At LEP the energy changes by $1.7 \cdot 10^{-5}$ for a transverse movement of 10 μm at the horizontally defocusing quadrupoles in the arcs.

The particles in LEP being ultra-relativistic, the length of their orbit is only determined by the frequency of the RF system. Since this frequency is kept constant during physics running, ring deformations will change the beam position in the quadrupoles and the beam energy. The beam position in the quadrupoles can be monitored with the beam position monitors (BPM) of LEP. To enhance the sensitivity and reduce systematic effects, the horizontal position is averaged over all pickups installed in the regular arc FODO cells (X_{ARC}). The behavior of X_{ARC} has been checked by varying the RF frequency and measuring the effect of tides and the response followed the theoretical predictions. The ring deformations of LEP due to tides have been recently remeasured using X_{ARC} and the results are in good agreement with measurements by resonant depolarization [1]. Figure 1 shows the evolution of X_{ARC} after correction of tides for 1993 and 1995. Some of the structures visible in figure 1 could be correlated to hydrostatic effects on the rock surrounding LEP and to the water level in nearby Lake Leman [2]. The structures are also well correlated with some of the energy variations detected by resonant depolarization. Including the BPM information into the LEP energy model significantly reduces the scatter of calibration data and model. It should be noted that the absolute scale of X_{ARC} between 1993 and 1995 could be shifted by about $\pm$ 30 μm. This absolute calibration is

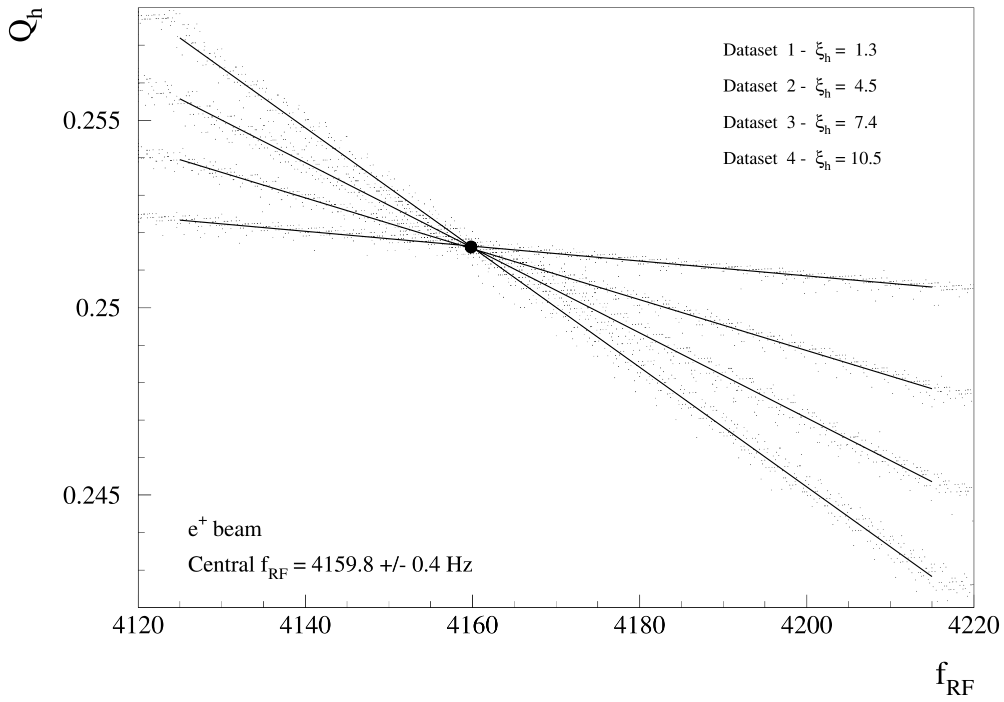

Figure 2: Example of a central frequency measurement at 20 GeV. The horizontal tune is plotted as a function of the RF frequency for different settings of the horizontal chromaticity. The crossing point determines the central frequency.

not critical since X_{ARC} only used to interpolate between energy calibrations of one LEP run. There is no need to interpolate from one year to another because the absolute energy scale is determined by resonant depolarization.

The circumference of the LEP ring can also be measured with the central RF frequency [3]. The principle consists in finding the RF frequency for which the horizontal tune of the machine does not depend on the horizontal chromaticity (figure 2). For this value of the RF frequency the beam is centered on *average* in the *sextupoles*. Since the sextupoles of LEP are mounted on the same girder than the quadrupoles next to each of them, the orbit will also be roughly centered in the quadrupoles. Central frequency measurements have to be performed with non-colliding beams because a clean tune spectrum is required for this measurement where the tune is tracked in a PLL mode. For this reason these measurements are performed either at injection or after physics. The accuracy can in principle reach $\pm$ 1 Hz. Figure 3 shows the correlation between central frequency measurements and X_{ARC}. With the exception of the 1994 data sample where a certain agreement is indeed present (although the data sample do not agree within their quoted errors), there is no correlation between the two measurement techniques [2, 4]. For the 1995 run, the central frequency measurements were perturbed by slow tune fluctuations with a period of about one minute. These fluctuations are small enough not to perturb the machine operation, but they make central frequency measurements with a reasonable accuracy very difficult. It must also be mentioned that controlled experiments have never been performed with the central frequency (monitoring tides or a controlled RF frequency shift).

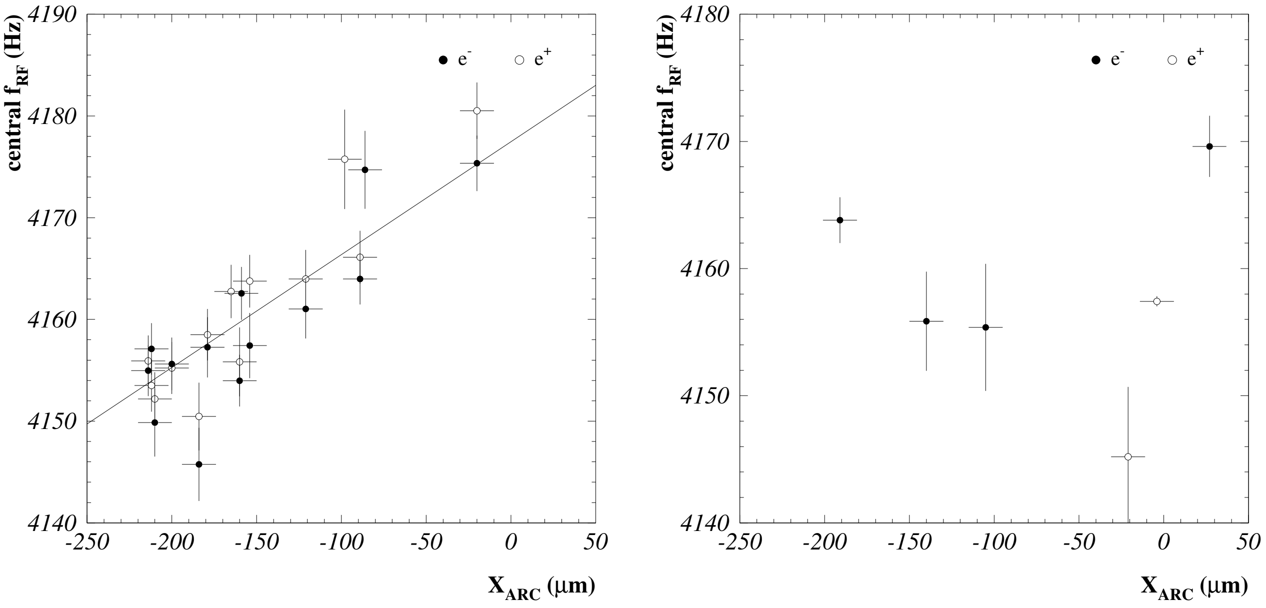

Figure 3: "Correlation" between the central frequency and the beam position data for 1994 (left) and 1995 (right). The slope has been fixed to 0.11 Hz/μm, as expected from the beam optics for 1994.

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[3] H. Schmickler, "Measurements of the Central Frequency of LEP", CERN SL-MD note 89 (1993).

[4] J. Wenninger, "Study of the LEP Beam Energy with Beam Orbits and Tunes", CERN SL/94-14 (BI).