

# LEP dynamic aperture with asymmetrical RF distribution

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**Abstract** The reduction of dynamic aperture for LEP 200 caused by an asymmetrical RF distribution is investigated by particle tracking. In particular, the dependence of this effect on synchrotron tune is studied under different conditions in case of break down of an RF unit. The localization of the accelerating cavities and the consequent discontinuous replacement of radiated energy are taken into account.

## 1 INTRODUCTION

Owing to synchrotron radiation, electrons and positrons lose energy almost uniformly along the arcs of the machine, while this radiated energy is restored by a few localized RF-stations. Therefore, even neglecting magnetic imperfections, the orbits of electrons and positrons are different: the maximum orbit separation scales with the cube of the particle energy and is inversely proportional to the number of RF-stations. The consequent gradient distortions induced in quadrupoles and sextupoles lead to optics perturbations and thus to a potential deterioration of the LEP performance.

In Section 2, we discuss the chromaticity correction of the 90° lattice and, in Section 3, the corresponding stability limits for different beam energies, synchrotron tunes and symmetries of the RF-system. For asymmetric RF-configurations, we find an unexpected dependence of the dynamic aperture on the choice of synchrotron tune. In particular, the reduction of dynamic aperture is clearly related to the appearance of instability stop-bands in betatron amplitude, which seem to exist even in the absence of radiation effects.

## 2 CHROMATICITY CORRECTION

The chromaticity correction of the 90° lattice with 4 sextupole families [1] has been improved by an optimisation of the weights appearing in the program HARMON [2], used to compute the sextupole strengths. In particular, the chromatic variation of the tunes has been globally kept below 0.03 for  $Q_x$  and 0.06 for  $Q_y$  over the relevant momentum range  $\Delta p/p = \pm 1.5\%$  (see Fig. 1), corresponding to 10 times the natural energy spread at 100 GeV. These curves should be compared to those of the 60° lattice (Fig. 3.1 in [3]), where the chromatic variation of  $Q_y$  over the same momentum range is almost double.

The stability limits discussed in the next section refer to the standard lattice LEP290H (with  $Q_x = 91.385$ ,  $Q_y = 97.285$  and  $\beta_y^* = 7$  cm, corresponding to n07h46 with 4 sextupole families) and are much higher than those presented in [4], where the chromaticity correction of the 90° lattice had not yet been optimized. A good correction has also been found for a vertical beta-function at interaction  $\beta_y^* = 4.3$  cm and for the modified insertions allowing the installation of super-conducting cavities. It should be stressed that the chromaticity correction is computed for an ideal machine without radiation effects, since the latter would be different for electrons and positrons.

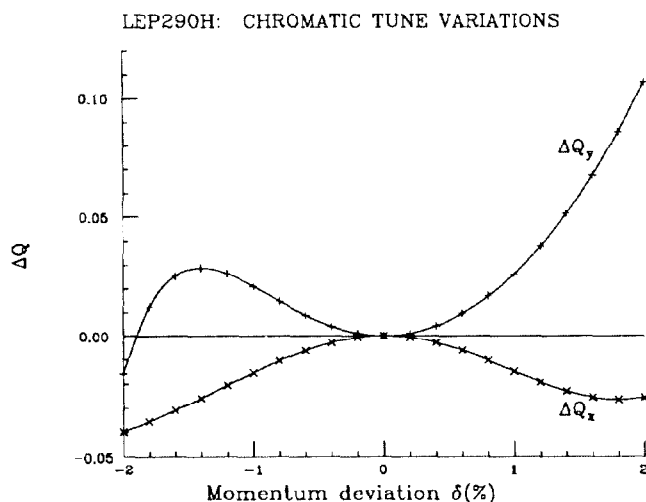


Figure 1: Tune variations with momentum.

## 3 DYNAMIC APERTURE

In Figs. 2–5, we show different stability limits obtained by particle tracking (with the program MAD [5]) over 400 turns in presence of aperture limiting collimators. In all cases, the effect of radiation on the closed orbit is included (whereas radiation damping and quantum excitation are neglected). Tracking is performed in presence of synchrotron oscillations and we make the pessimistic assumption of full coupling.

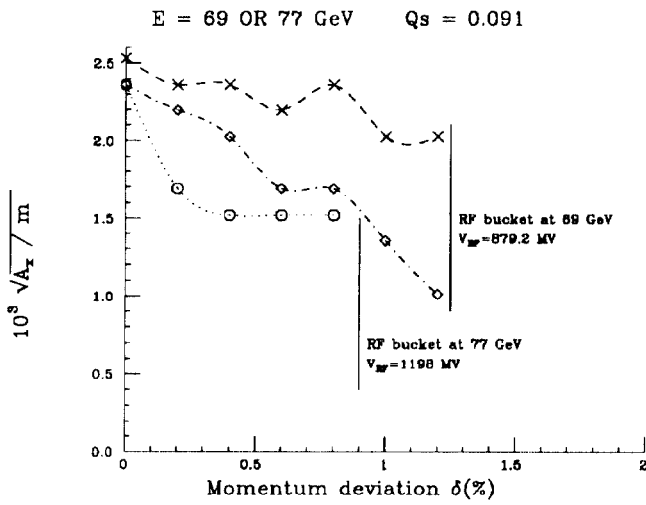


Figure 2: Dynamic aperture versus momentum deviation at 69 GeV with 4 RF-stations (crosses), with 2 RF-stations (diamonds) and at 77 GeV with 2 RF-stations (circles).

The three curves in Fig. 2 show the difference between the case of 2 and 4 RF-stations at an energy of 69 GeV and give the dynamic aperture for the maximum energy (77 GeV) which should be reached with only 2 RF-stations around the interaction points 2 and 6; this aperture turns out to be still sufficient to operate LEP with a good beam life-time. In all cases, the synchrotron tune is assumed to be  $Q_s = 0.091$ .

In Fig. 3 we consider an energy of 84 GeV, showing the dynamic aperture in the case of 4 RF-stations symmetrically distributed around the interaction points (upper curve) or for less symmetric situations: two of the lower curves refer to the case where the RF-voltage around points 4 and 8 is twice or three times the voltage around points 2 and 6 (always keeping the left-right symmetry around each IP). The synchrotron tune is  $Q_s = 0.122$ , corresponding to a total accelerating voltage of 1920 MV and to an energy acceptance of the RF-bucket around 1.7%. The remaining lower curve refers to the (originally) symmetric case with a tripped RF-unit: this corresponds to a voltage drop of 120 MV on the left or on the right of one of the interaction points and to a synchrotron tune  $Q_s = 0.113$ . The energy acceptance of the RF-bucket is reduced to 1.5%.

In Fig. 4 we show similar curves for an energy of 100 GeV and a comparable value of the synchrotron tune  $Q_s = 0.119$ , corresponding to a total accelerating voltage of 3200 MV and to an energy acceptance of the RF-bucket around 1.2%. It can be seen that even a deviation by a factor two from the 4-fold symmetry leads to a severe reduction of dynamic aperture. In the case of a tripped RF-unit, corresponding to a voltage drop of 200 MV on the left or on the right of one of the interaction points and to a synchrotron tune  $Q_s = 0.098$ , the energy acceptance of the RF-bucket is reduced to 0.7%, i.e. to less than five times the natural energy spread.

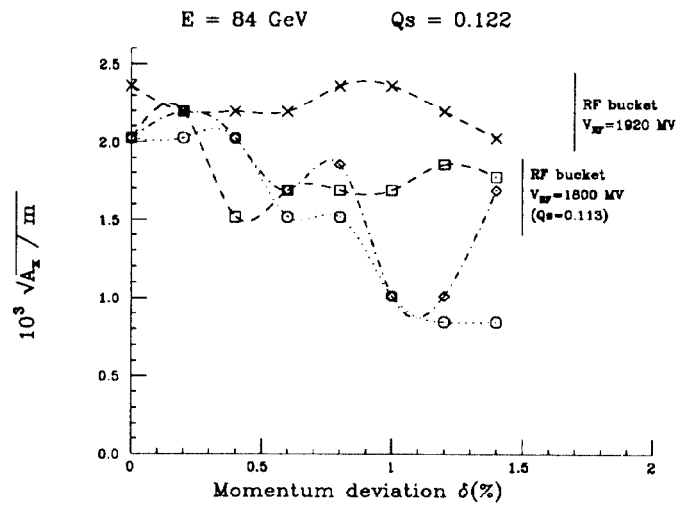


Figure 3: Dynamic aperture versus momentum deviation at 84 GeV: with 4 symmetric RF-stations (crosses), with an asymmetry in the voltage at points IP4-IP8 with respect to IP2-IP6 (ratio 2 to 1: diamonds, ratio 3 to 1: circles), with a tripped RF-unit (squares).

Finally, in Fig. 5, we consider again the case of 100 GeV but for a larger value of the synchrotron tune  $Q_s = 0.141$ , corresponding to a total accelerating voltage of 3520 MV and to an energy acceptance of the RF-bucket larger than 1.5%. In this case, the reduction of dynamic aperture is tolerable even for a deviation by a factor three from the 4-fold symmetry. The lower curve refers to the (originally) symmetric case with a tripped RF-unit: this corresponds to a voltage drop of 220 MV and to a synchrotron tune  $Q_s = 0.127$ . The energy acceptance of the RF-bucket is not much reduced, but there is a significant loss of dynamic aperture.

The unexpected dependence of the dynamic aperture on the choice of synchrotron tune (for asymmetric RF-configurations) is currently under investigation, as well as the dependence of these results on the choice of working point. There is a clear relation between the reduction of dynamic aperture and the appearance of instability stop-bands in betatron amplitude, which seem to exist even in the absence of radiation effects (see also [6, 7]). For example, Fig. 6 shows the stability limit obtained by tracking with 2 RF-stations and  $Q_s = 0.091$  (corresponding to the lowest two curves in Fig. 2) in the absence of synchrotron radiation. The instability stop-band, whose shape and position depends on the choice of 400 turns for the particle survival time, limits the useful dynamic aperture at large momentum deviations down to values comparable to those obtained including radiation effects at 69 or at 77 GeV.

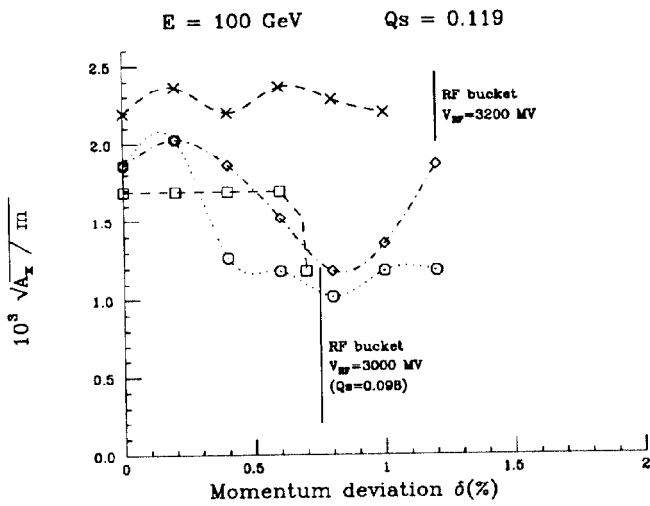


Figure 4: Dynamic aperture versus momentum deviation at 100 GeV and  $Q_s = 0.119$ : with 4 symmetric RF-stations (crosses), with an asymmetry in the voltage at points IP4-IP8 with respect to IP2-IP6 (ratio 2 to 1: diamonds, ratio 3 to 1: circles), with a tripped RF-unit (squares).

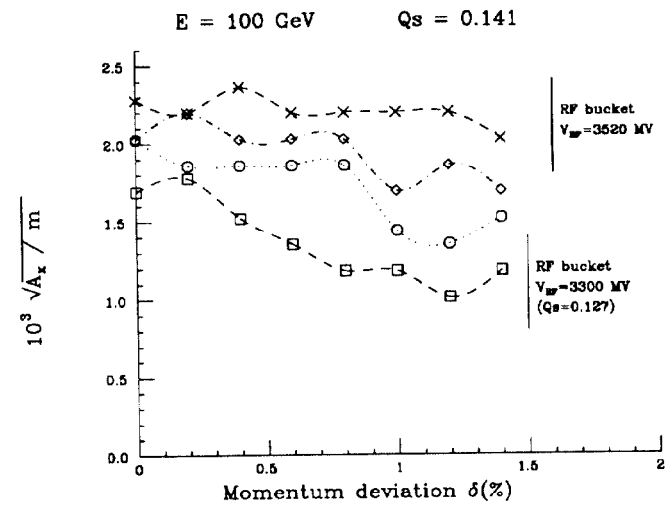


Figure 5: Dynamic aperture versus momentum deviation at 100 GeV and  $Q_s = 0.141$ : with 4 symmetric RF-stations (crosses), with an asymmetry in the voltage at points IP4-IP8 with respect to IP2-IP6 (ratio 2 to 1: diamonds, ratio 3 to 1: circles), with a tripped RF-unit (squares).

By a further optimization of the sextupole strengths, at constant chromaticity, it is possible to substantially increase the survival time in the stop-band. In the case of Fig. 6, for example, the survival time at  $\delta = 1\%$  can be increased from 130 to 260 turns by a relative change of  $\pm 4\%$  in the strengths of the two focusing sextupole families. Since the betatron damping time at 77 GeV is about 150 turns, a survival time of 260 turns is sufficient for particle stability.

## References

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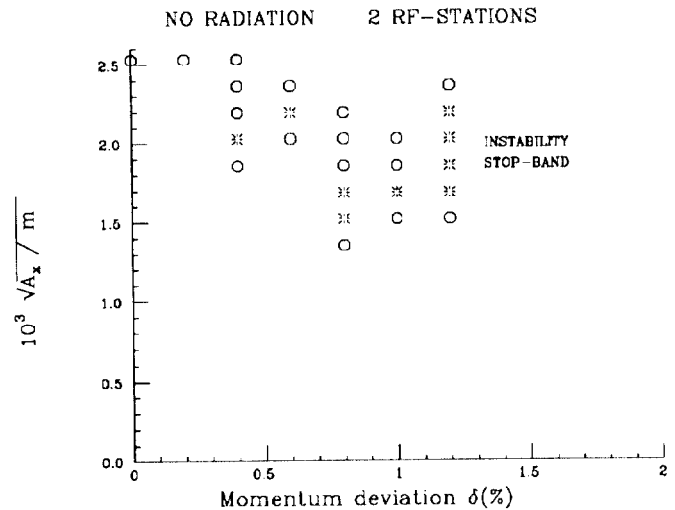


Figure 6: Stability limit with no synchrotron radiation and 2 RF-stations at  $Q_s = 0.091$ : circles denote particles surviving at least 400 turns, whereas stars in the instability stop-band correspond to particles typically lost after 100-200 turns.