LEP Note 629

# Compensation of Integer Spin Resonances Created by Experimental Solenoids

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## Abstract

Local orbit bumps effective at compensating the large integer spin resonances generated by the experimental solenoids on transverse polarization are described. The bumps introduce only local distortion of the closed orbit and of the vertical dispersion. The local distortions are 6mm vertical offset and 6cm vertical dispersion. Three existing vertical correctors situated in the arcs on each side of the experimental straight sections can be used. The maximum kick required is 104 microradians to compensate a solenoid of integrated field strength of 10 T.m. The resulting depolarization, in a machine with all four solenoids active and corrected, is $\tau_p/\tau_d \leq 0.3$. This is much smaller than the depolarization due to lattice imperfections, and should allow transverse polarization to be optimized during normal physics runs.

## 1 Introduction

The transverse polarization builds up naturally in an $e^+e^-$ storage ring by Sokolov-Ternov process [1]. Its conservation depends critically on the fact that all fields encountered around the orbit are vertical. The presence of very strong experimental solenoids induces a rotation of the spin vector around the longitudinal field direction. The largest solenoidal field in LEP, that of the ALEPH experiment, has an integrated field of 10 T.m, causing a rotation of $\frac{\pi}{2} \times \frac{10}{2.3\times\nu} = 0.066$ radians. $\nu$ is the spin tune, $\nu = a\gamma \simeq 104$ at the Z peak energy. This rotation is not compensated by the skew-quadrupoles used to compensate the effect of the solenoid on the betatron oscillations. As a result, it generates very large spin resonances, and almost complete depolarization as shown on figure 1.

It is of great interest to correct for this effect, so that polarization studies can also take place during normal physics runs with solenoids on, and not only during machine development time, which is scarce.

## 2 Design of the correctors

The principle of the spin-compensation of the solenoid by spin rotators situated in the arcs has been sketched by Rossmanith [2]. It consists in implementing a small spin rotator at each end of the experimental straight sections, each generating a rotation of the spin equal to one half of that produced by the solenoid, and opposite to it. Rossmanith suggests to realize this by a succession of vertical corrector–normal arc bend–vertical corrector. A practical application of this principle has been sought here.

In previous studies, it has been observed that vertical orbit bumps, involving *existing* vertical correctors, could be used as small spin rotators, to compensate the integer spin resonances, see for instance [3] for the case of LEP. The simple bump consisting of two vertical correctors separated by a vertical phase advance of $\pi$ has the advantage that it creates no vertical orbit displacement anywhere else than within the bump itself. However, it generates a spurious vertical dispersion all around the ring. This latter inconvenient can be easily overcome if one uses two such bumps of equal amplitude next to each other, figure 2. The double bump so obtained leaves both the orbit and the dispersion unaffected in the rest of the machine. This is a substantial operational advantage, considering the effect of vertical dispersion in RF cavities or wigglers, and the effect of the vertical orbit on backgrounds in the experiments.

A double-bump is characterized by the kick $\kappa$ in, say, the first corrector. The last corrector is excited to the same value, and the middle one to $2 \times \kappa$

The implementation of such a double bump in the dispersion suppressor is not trivial (yet not impossible); it is very easy in the arcs, so this is the solution that I chose. Starting with the LEP13 file of the first order polarization program SLIM [4], and a perfect machine, I added at first the strongest solenoid (ALEPH's) with the corresponding skew-quadrupoles, and studied the problem at $\nu = 103.54$, i.e. $E_{beam} = 45.625$ GeV. The machine has the following tunes: $Q_x = 70.39, Q_y = 78.23, Q_s = 0.09$.

The double-bump closest to the dispersion suppressor was chosen, and its amplitude varied until the polarization degree was optimal. A value of $\kappa = 52$ microradians was found, leading to a polarization degree of 67%

It is convenient to discribe depolarizing effects in term of the depolarizing strength, inverse of the depolarizing time $(1/\tau_d)$, and to compare it with the strength of polarizing effects, inverse of the theoretical polarization time $(1/\tau_p)$. The ratio $\tau_p/\tau_d$ is related to the asymptotic degree of polarization, $P_\infty$, and to the effective polarization time, $\tau_p^{\mathrm{eff}}$, by the relations:

$$P_\infty = 0.924 \times \frac{1}{1 + \tau_p/\tau_d} \qquad (1)$$

$$\tau_p^{\mathrm{eff}} = \tau_p \times \frac{1}{1 + \tau_p/\tau_d} \qquad (2)$$

Both the asymptotic polarization and the time it takes to reach it are reduced by depolarizing effects in the same proportion. Depolarizing effects from various sources are usually additive.

| Configuration | $(\tau_p/\tau_d)_{all}$ | $(\tau_p/\tau_d)_s$ | $(\tau_p/\tau_d)_x$ | $(\tau_p/\tau_d)_y$ | Polarization (%) |
|---|---|---|---|---|---|
| Four solenoids, no correction wigglers OFF | 144.4 | 144.2 | 0.980 | 0.090 | 0.6 |
| ALEPH solenoid , corrected wigglers OFF | 0.37 | 0.028 | 0.335 | 0.015 | 67.2 |
| Four solenoids, corrected wigglers OFF | 0.28 | 0.023 | 0.314 | 0.108 | 72.6 |
| Four solenoids, corrected wigglers ON | 0.044 | 0.026 | 0.027 | 0.009 | 87.2 |

Table 1: Strength of depolarizing effects in various configurations. The Z peak energy has been chosen: $E_{Beam} = 45.62$ GeV, spin tune $\nu = 103.53$. The theoretical polarization time $\tau_p$ is 330 minutes with polarization wigglers OFF and 36 minutes with polarization wigglers ON.

A degree of polarization of 67% corresponds to a depolarization strength of $\tau_p/\tau_d \simeq 0.3$. For comparison, it is expected that the machine imperfections in the real machine lead to depolarizing effects of a strength of $\tau_p/\tau_d \simeq 10 - 100$, or even worse. The degree of polarization as a function of spin tune is shown in figure 3.

By examining the depolarization associated to the various oscillations, it was found, as expected, that the bumps act on the depolarization created by integer resonances and their synchrotron satellites, as shown in table 1. The behavior of the various modes of depolarization as a function of spin tune is shown in figure 3. The optimal excitation of the corrector is energy dependent: $\kappa = 51.9$ microradians is optimal around $\nu = 104$, while $\kappa = 54.0$ microradians is optimal around $\nu = 103$.

The effect of the optimal bump on the spin motion is exactly as anticipated by Rossmanith: take a vertical spin from the arc, have it arrive to the straight section with an angle with the vertical (y-s) plane half of that caused by the solenoid. The spin vector at the interaction point (IP) is in the vertical plane. The motion is symmetric around the IP and the spin then goes back to vertical after the second bump.(figure 4).

For the ALEPH magnet, 10.082 T.m, a vertical kick of $\kappa = 51.9$ microradians is required. This is a very reasonable field for the existing vertical correctors, and requires no new hardware. As intended in the design, they generate no parasitic orbit distortion or vertical dispersion outside the bumps themselves. Within the bumps, very reasonable values of 6mm for the vertical orbit, and 6cm for the vertical dispersion, are observed. As a consequence, this correction can be tried, and hopefully implemented, right away.

The validity of the correction procedure was supported by the installing all four experimental solenoids, their skew-quads as provided by H. Moshammer according to ref. [5], and their spin correctors scaled in exact proportion to the field integral of the solenoid, as detailed in table 2.

The resulting polarization is shown in figure 5. The correction works. The agreeable surprise is that the depolarization due to horizontal betatron resonances remains at the same level, while vertical resonances are, not unexpectedly, reinforced. They originate in

| Corrector | abscissa (m) | kick strength (microradians) |
|---|---:|---:|
| CV.QD32.L2 | 2336.392 | 31.3 |
| CV.QD26.L2 | 2573.392 | 62.6 |
| CV.QD20.L2 | 2810.392 | 31.3 |
| Solenoid point 2 | 3332.359 | (6.078 T.m) |
| CV.QD20.R2 | 3854.327 | -31.3 |
| CV.QD26.R2 | 4091.327 | -62.6 |
| CV.QD32.R2 | 4328.327 | -31.3 |
| CV.QD32.L4 | 9001.110 | 51.9 |
| CV.QD26.L4 | 9238.110 | 103.8 |
| CV.QD20.L4 | 9475.110 | 51.9 |
| Solenoid point 4 | 9997.077 | (10.082 T.m) |
| CV.QD20.R4 | 10519.045 | -51.9 |
| CV.QD26.R4 | 10756.045 | -103.8 |
| CV.QD32.R4 | 10993.045 | -51.9 |
| CV.QD32.L6 | 15665.827 | 13.45 |
| CV.QD26.L6 | 15902.827 | 26.90 |
| CV.QD20.L6 | 16139.827 | 13.45 |
| Solenoid point 6 | 16661.795 | ( 2.613 T.m) |
| CV.QD20.R6 | 17183.762 | -13.45 |
| CV.QD26.R6 | 17420.762 | -26.90 |
| CV.QD32.R6 | 17657.762 | -13.45 |
| CV.QD32.L8 | 22330.545 | 46.5 |
| CV.QD26.L8 | 22567.545 | 93.0 |
| CV.QD20.L8 | 22804.545 | 46.5 |
| Solenoid point 8 | 23326.512 | ( 9.030 T.m) |
| CV.QD20.R8 | 23848.480 | -46.5 |
| CV.QD26.R8 | 24085.480 | -93.0 |
| CV.QD32.R8 | 24332.480 | -46.5 |

Table 2: Location and excitation of the solenoid correctors, for LEP13 at $E_{Beam} = 45.625$ GeV.

the vertical bumps themselves and cannot be avoided. They remain at a very reasonable level, however.

This correction only acts on integer resonances and their synchrotron satellites. It is ineffective against the horizontal betatron resonances, which dominate the remaining depolarization effects. The reason for this can be found, presumably, in the fact that the section of machine between the correctors is not spin-transparent anymore. Indeed, Rossmanith describes a spin-matching condition for horizontal betatron oscillations. This condition cannot be applied to the practical system as it is written, but a similar condition on the horizontal phase advance in the straight section probably exists. Performing this spin-matching is impractical in SLIM, and will have to be performed with more realistic machine parameters anyway. One can note in passing that this is exactly the kind of effect that can be strongly suppressed with the polarization wigglers, as shown in figure 6, and table 1.

## 3 conclusion

It seems possible to implement a system that ensures sufficient spin compensation of the solenoids at no cost, with existing hardware, and with a priory no interference with the performance of the machine, and in particular no effect on the orbit or the vertical dispersion. More work on the spin-matching of horizontal betatron oscillations is still needed if one wants to reach a very high degree of transverse polarization, but the correction proposed here is probably sufficient at the beginning, when low (below about 30%) polarization degrees are considered.

## References

[1] A. A. Sokolov and I. M. Ternov, Sov. Phys. Doklady, 8 (1964) p. 1203.

[2] R. Rossmanith, LEP Note 525 (1985)

[3] A. Blondel and J.M. Jowett, LEP-note 606 (1988);
J.-P. Koutchouk and T. Limberg, in 'Polarization at LEP', G. Alexander et al. (editors), CERN 88-06 (1988), vol.II, p. 204.

[4] A. Chao, Nucl. Instr. Meth. 180 (1981), p. 29.

[5] J.-P. Koutchouk, LEP-note 480 (1983).

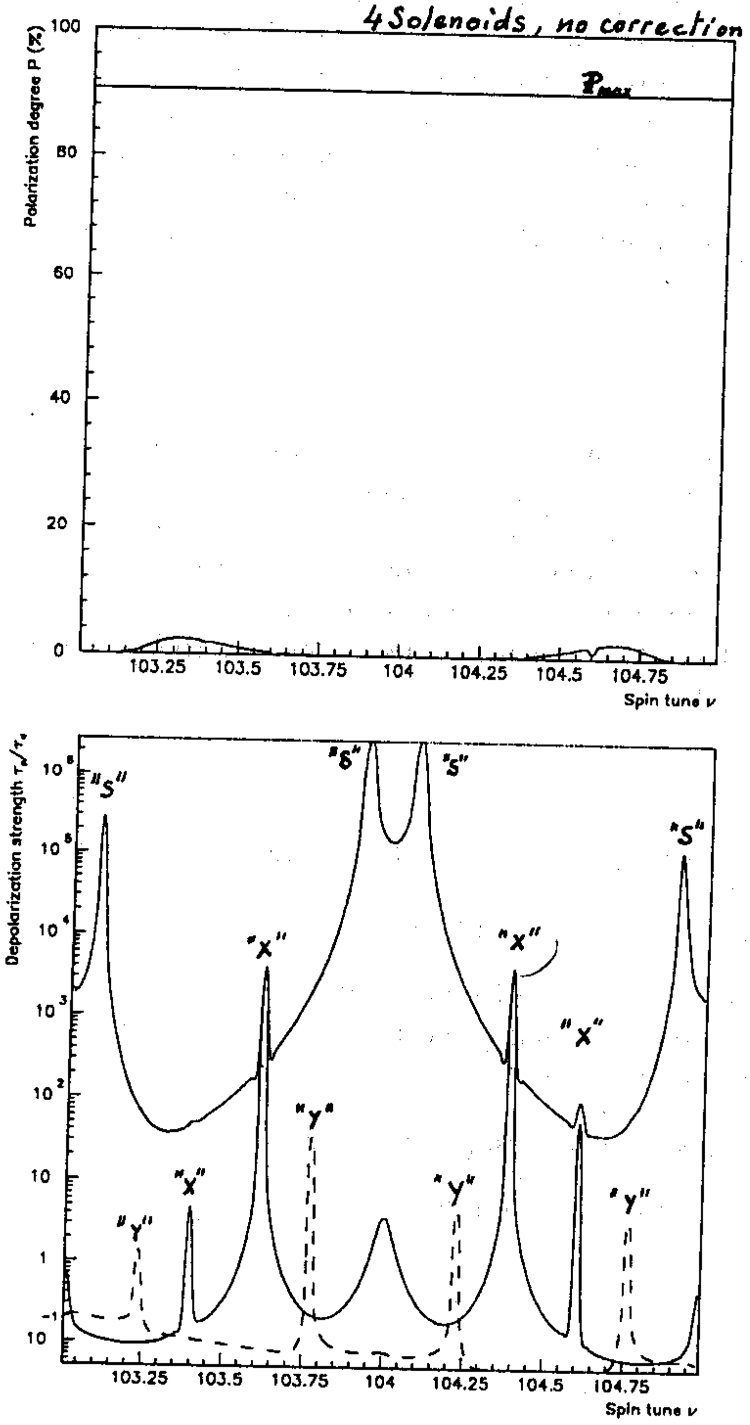

Figure 1: Effect of uncorrected solenoids: polarization as a function of spin tune, and components of the depolarization. LEP13 with four uncorrected solenoids, no wigglers, and no imperfections.

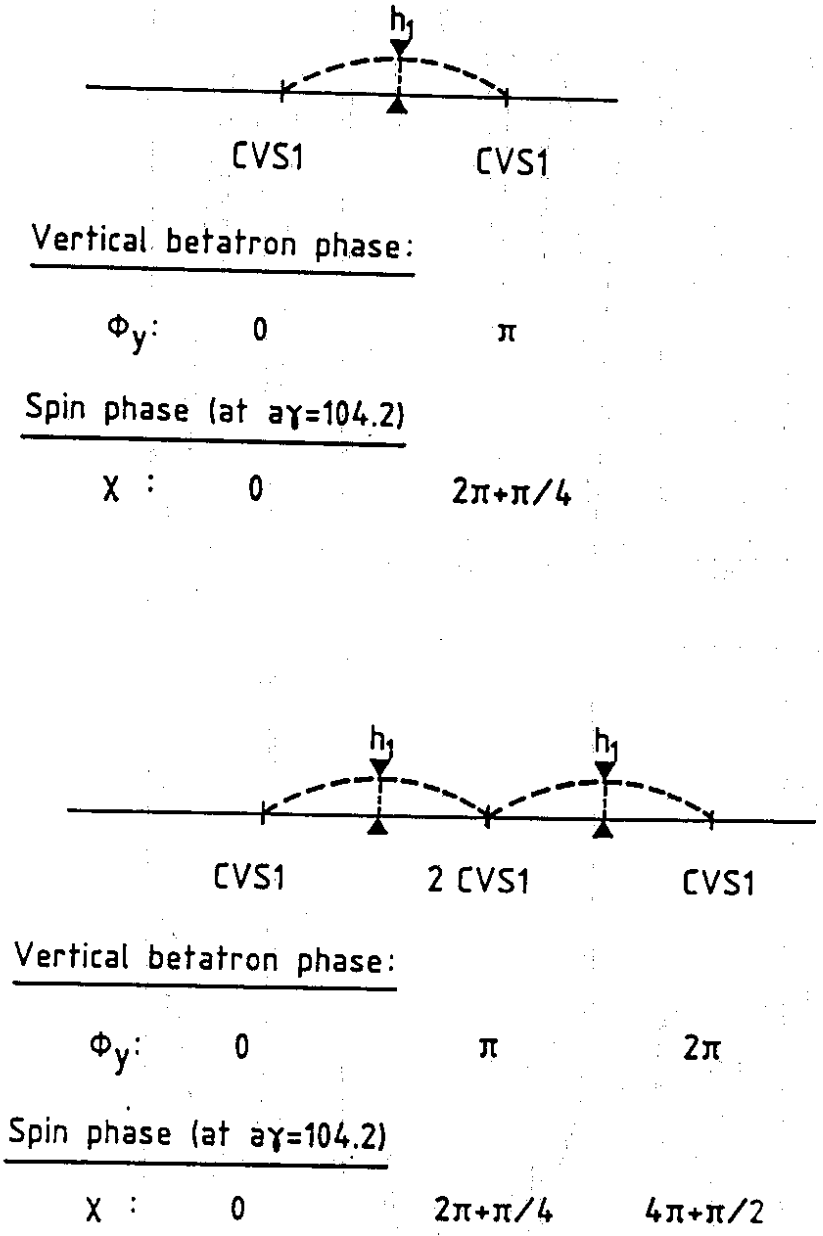

Figure 2: Sketch of the simple bump spin rotator, where vertical dispersion propagates throughout the machine, and of the double-bump spin corrector, where no vertical dispersion propagates.

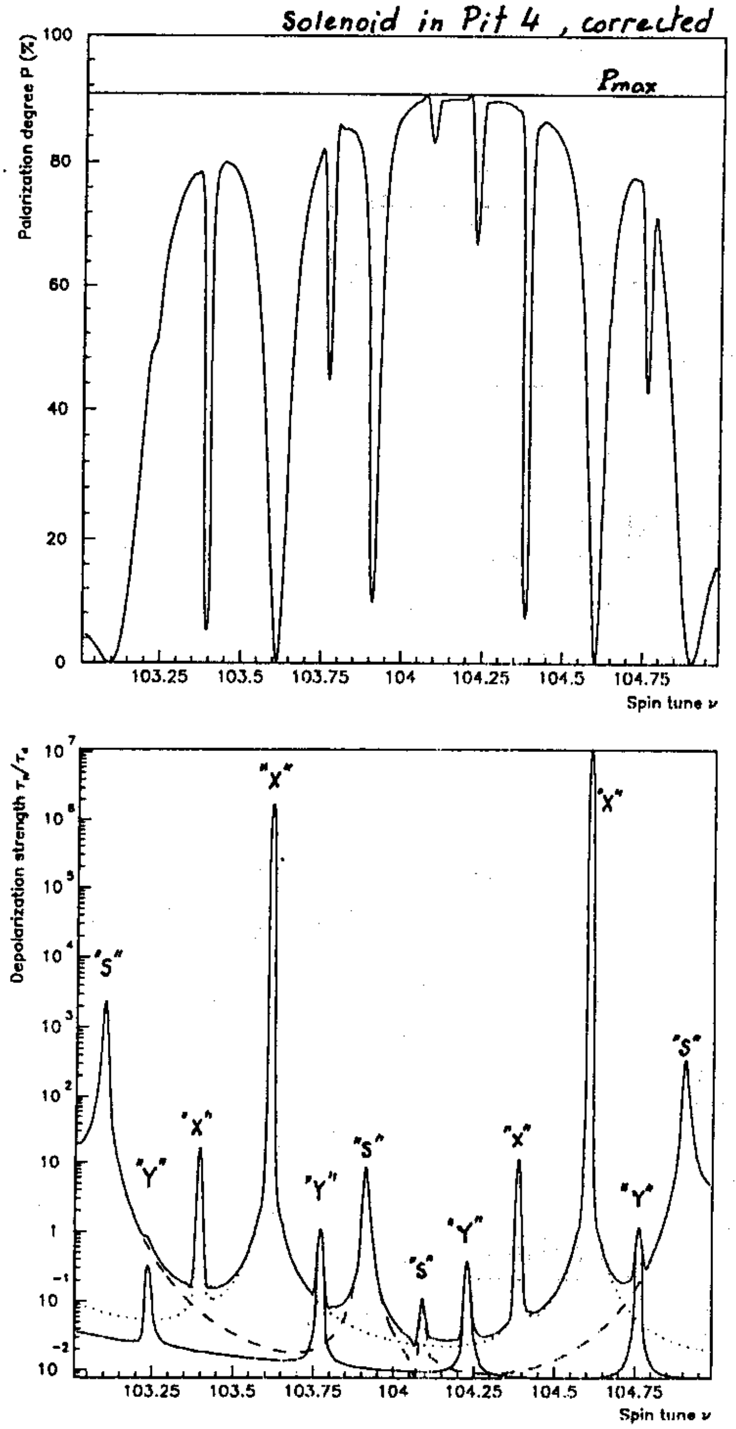

Figure 3: Top: polarization degree as a function of the spin-tune in LEP, equipped with one 10 T.m solenoid, and the spin correctors with a kick of 51.9 microradians. Perfect machine with no wigglers.
Bottom: depolarization effects.
full line: all sources.
dashed line: integer resonances and synchrotron oscillations, labeled "s".
dotted line: horizontal betatron oscillations, labeled "x".
thin line: vertical betatron oscillations, labeled "y" .

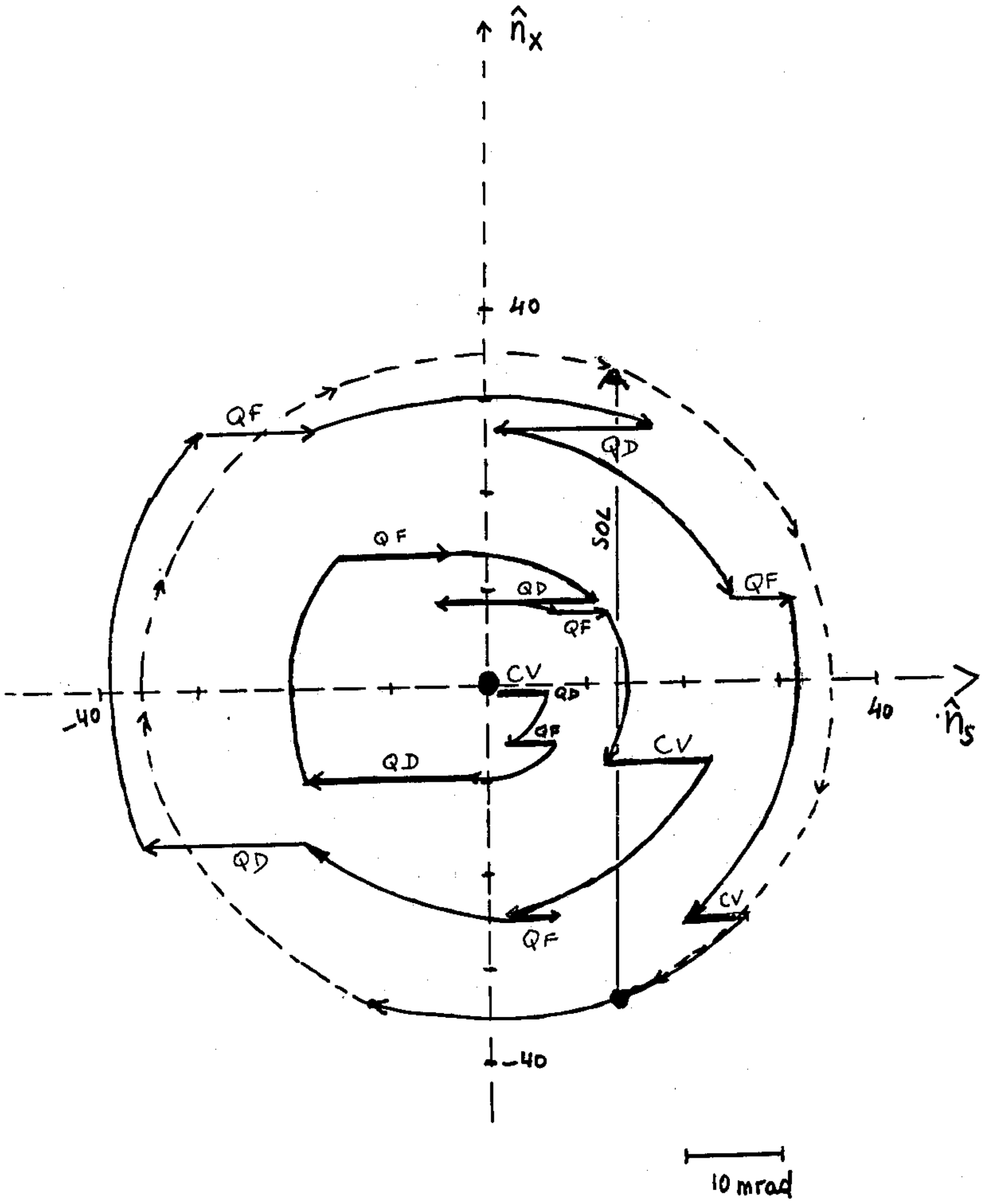

Figure 4: Movement of the spin vector in one half of the proposed spin corrector.

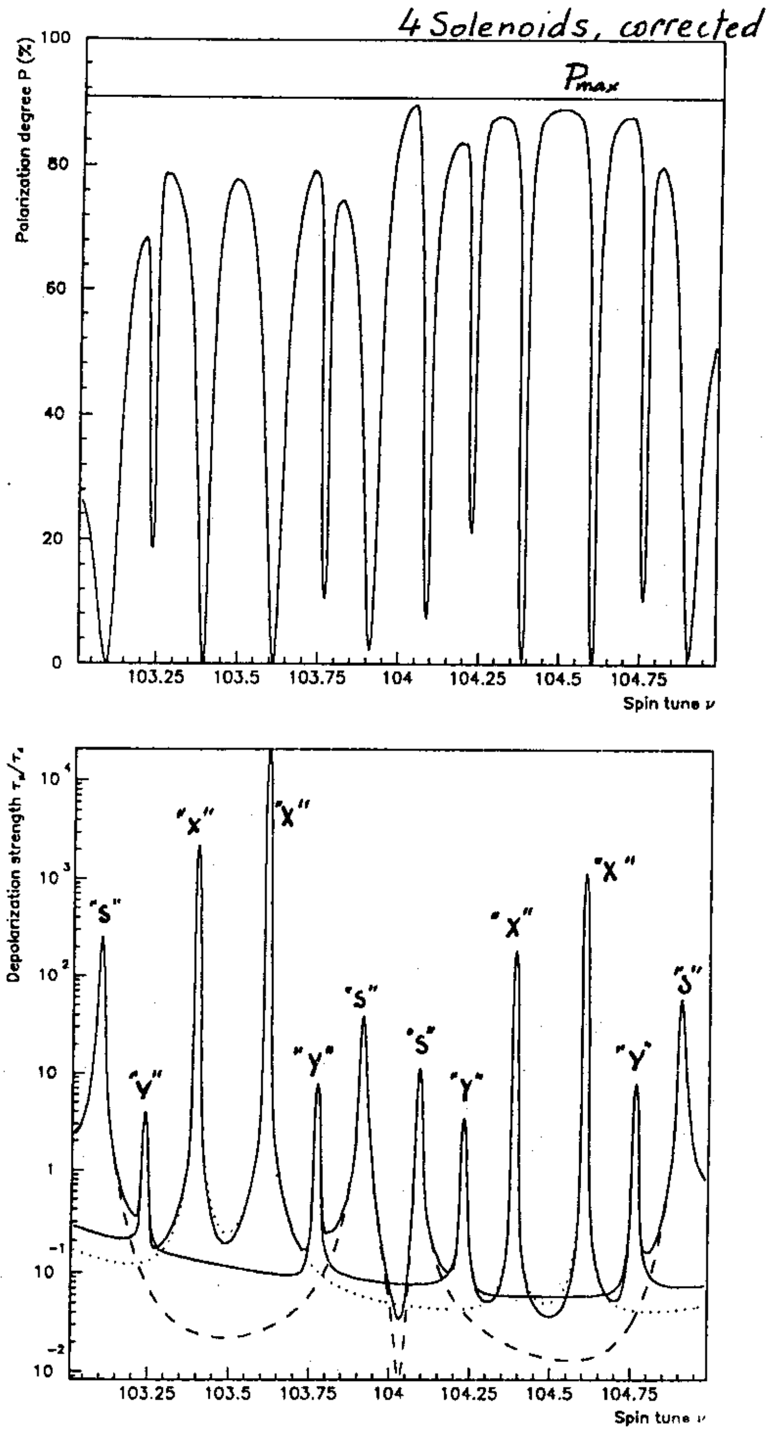

Figure 5: Top: polarization degree as a function of the spin-tune in LEP, equipped with the four experimental solenoids and four spin correctors tuned for $\nu = 104$. Perfect machine with no wigglers.
Bottom: depolarization effects.
full line: all sources.
dashed line: integer resonances and synchrotron oscillations, labeled "s".
dotted line: horizontal betatron oscillations, labeled "x".
thin line: vertical betatron oscillations, labeled "y" .

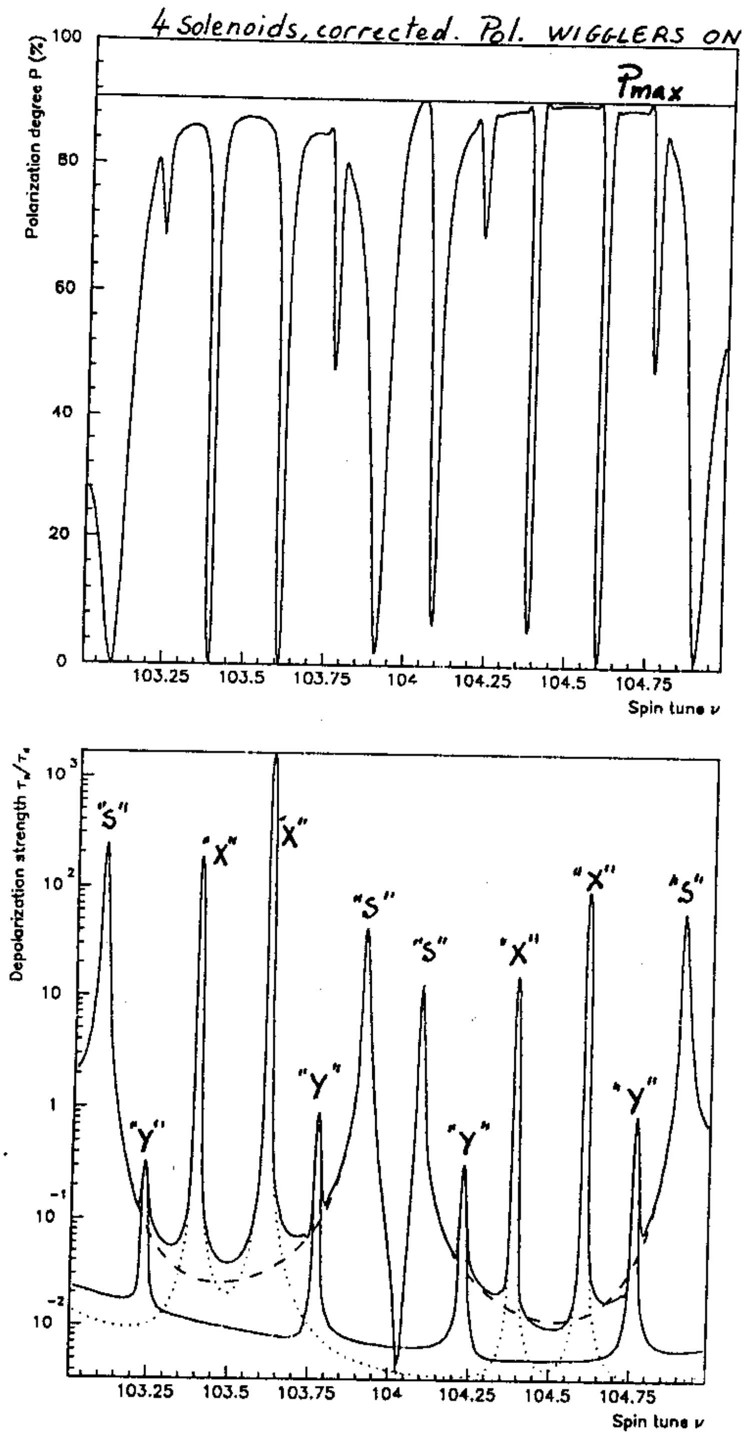

Figure 6: Reduction of the remaining depolarizing effects with the wigglers. Same as figure 5, but in a machine with dedicated polarization wigglers yielding a polarization time of 36 minutes.