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Letter of Intent
A Test of Longitudinal Spin Polarization at LEP

Preliminary list of authors:
A. Blondel[1)], J.-C. Brient[1)], M. Dam[7)], C. Grupen[8)], R. Jacobsen[3)], D. Lellouch[1)2)], G. Mikenberg[2)], D. Plane[3)], B. Pietrzyk[5)], J. Rander[6)], A. L. Read[7)], D. Schlatter[3)], J.-P. Schuller[6)], J.-J. Veillet[4)], I. Videau[4)].

Abstract

In view of recent successes in the LEP polarization programme, the interest of longitudinal polarization is reconsidered. Contrary to SLC where the beam polarization has to be measured separately, the availability of polarization for both e^+ and e^- beams in LEP renders the measurement of the left-right polarization asymmetry A_{LR} self-calibrating, thus essentially free of systematic errors. Given the high statistical power of A_{LR}, LEP could obtain eventually the most precise and safest measurement of the weak mixing angle. This makes the implementation of longitudinally polarized beams in LEP highly worthwhile.

In order to make use of this asset, the following steps are proposed.

1. The major unknown is presently the degree of beam polarization that can be sustained with luminosity conditions. **Machine studies of the effect of beam-beam collisions on transverse polarization should be scheduled with high priority as soon as possible in 1994.**

2. A downscaled version of the Richter-Schwitters spin rotator has been studied and is presented here. Situated in point 1, it does not require civil engineering. It does not interfere with tests of superconducting RF cavities up to at least 70 GeV beam energy. **Final design should be carried out as soon as possible to allow a possible test of spin rotation in 1995.**

3. In order to test the feasibility of longitudinal polarization experiments, the test spin rotator area should be instrumented with background monitors, luminosity counters and a rudimentary Z counter. Members of the LEP collaborations would be involved in the operation of this equipment. **Further studies towards instrumentation of the rotator test area should be encouraged.**

Successful completion of these steps would clearly enrich the physics potential of LEP, and could already provide a meaningful measurement of $\sin^2 \theta_w^{\text{eff}}$ in 1995.

[1] Ecole Polytechnique, Palaiseau, France.
[2] Weizmann Institute of Science, Rehovot, Israel.
[3] CERN, Geneva, Switzerland
[4] LAL, Orsay, France
[5] LAPP, Annecy, France
[6] DAPNIA, Saclay, France
[7] University of Oslo, Norway
[8] Universität Siegen, Germany

1 Introduction

The physics case for longitudinally polarized beams has been emphasized on several occasions in the past [1, 2, 3]. A large amount of material can be found, in particular, in the CERN Yellow Report "Polarization at LEP" [3]. Substantial progress has been achieved since.

1. Due to the careful re-alignment of LEP and upgrade of the Beam Orbit Monitor system (BOM) the harmonic analysis of the LEP closed orbit for compensation of lattice defects [4, 5, 6] is now possible. This has allowed the recently observed [6] high degree of transverse polarization of 55%.
2. Solenoid compensation [7, 8], has been achieved.
3. Polarization, as expected, is well compatible with the Pretzel scheme to increase the number of bunches and the luminosity of LEP.
4. Practical experience has been gained on the beam polarization measurement [9].
5. The LEP physics runs turn out to last much longer (12 hours or more), with a more constant luminosity, than anticipated (3 hours at the time of ref. [3]). This time is now comfortably longer than the asymptotic polarization rise time of 5 hours.
6. The luminosity measurements by LEP experiments have now reached (or will reach) an experimental precision of 10^{-3} [10], *absolute*. They are perfectly suitable for a systematics free and statistically optimal measurement of the beam polarization asymmetry A_{LR}.

This report is organized as follows. First, the possible performance of LEP in terms of effective polarization is evaluated. The measurement of A_{LR} is described next, showing that LEP can ultimately provide the best and safest measurement of electroweak mixing angle $\sin^2\theta_w^{\rm eff}$. The competition from SLC/SLD, unpolarized LEP and theoretical uncertainties is then discussed. We then stress the two remaining elements missing for performing polarization experiments in LEP. This leads to propose a sequence of experiments. A preliminary layout of a downscaled prototype spin-rotator is then described briefly[1)] as well as the equipment required to perform a meaningful test.

Our requests to the LEPC are the following:

1. Schedule studies of the effect of beam-beam interaction on the polarization with high priority as soon as possible in 1994.
2. Encourage the preparatory work to begin soon so that a test experiment could take place before the end of 1995.

If these requests are fulfilled we intend to present a more complete proposal in a few months.

2 Potential of the measurement of A_{LR} at LEP

Longitudinal polarization at the Z pole gives access to several important measurements as studied for LEP in [3] or SLC [11]. The most essential quantity that it provides is the left-right polarization asymmetry, A_{LR} which measures the change in total cross-section upon reversal of the beam helicity. There is a one-to-one correspondence between A_{LR} and the weak mixing angle $\sin^2\theta_w^{\rm eff}$:

$$A_{LR} = \frac{1}{\mathcal{P}}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \simeq \mathcal{A}_e \equiv \frac{2(1-4\sin^2\theta_w^{\rm eff})}{1+(1-4\sin^2\theta_w^{\rm eff})^2} \tag{1}$$

[1)] A more detailed document of the spin-rotator will be distributed after the Chamonix workshop on LEP performance.

where σ_L, σ_R are the cross-sections for left- or right-handed beams, and $\mathcal{P}$ is the beam polarization. This quantity is independent on the decay mode of the Z, up to effects due to the photon exchange terms, that are substantial only in the case of electron final state. As stressed in [3], other measurements of great interest can be obtained with final state asymmetries, especially for heavy quark physics. The LEP experiments are extremely well placed to perform measurements involving final state reconstruction. We will concentrate in the following on the determination of A_{LR} which is the most demanding on machine performance and polarization measurement.

To achieve a good precision on A_{LR} requires a combination of high polarization and high statistics, and a precise knowledge of the beam polarization.

$$\Delta A_{LR} = \frac{1}{\mathcal{P}} \frac{1}{\sqrt{N}} \oplus \frac{\Delta \mathcal{P}}{\mathcal{P}} \tag{2}$$

We examine in the following the possible performance of LEP in terms of luminosity and polarization, then show how the specificity of LEP to have both e^+ and e^- polarized allows good control on the beam polarization measurement. Then we compare the precision obtainable on $\sin^2 \theta_w^{\text{eff}}$ from A_{LR} with that obtainable from SLC and LEP without polarization, and with theoretical errors.

2.1 Effective polarization degree and performance

In presence of depolarizing effects, the asymptotic polarization is reduced in the same proportion as the effective polarization time according to the formulae:

$$P_\infty = 0.924 \times \frac{1}{1 + \frac{\tau_p}{\tau_d}} \tag{3}$$

$$\tau_p^{\text{eff}} = \tau_p \times \frac{1}{1 + \frac{\tau_p}{\tau_d}} \,. \tag{4}$$

The quantity $\frac{\tau_p}{\tau_d}$ represents the strength of depolarizing effects. The natural polarization time τ_p is very long at LEP, 300 minutes for the Z pole energy. The degree of polarization reached recently, 55%, corresponds to a fitted asymptotic value of $57 \pm 3\%$, e.g. $\frac{\tau_p}{\tau_d} = 0.62 \pm 0.08$.

It is difficult to predict what value of $\frac{\tau_p}{\tau_d}$ could be maintained for polarization experiments. The above value was obtained with a very rudimentary spin-compensation of the solenoids [7] giving an incompressible depolarization of $\frac{\tau_p}{\tau_d} = 0.3$. Given that depolarization sources lead to contributions to $\frac{\tau_p}{\tau_d}$ which add up linearly, straight-forward improvement is expected from implementation of complete spin-matching conditions. Also, improvements in correcting lattice imperfections are still to come. However, the high polarization of 55% was obtained with only one beam in the machine, and beam-beam collisions are certainly expected to degrade it.

Clearly further tests with collisions are necessary to clarify the issue. Bearing in mind this uncertainty, a value of $\frac{\tau_p}{\tau_d} = 0.7$, e.g. $P_\infty = 0.54$, will be assumed in the following.

One of the best surprises when LEP started was the extremely long beam lifetime, much better than assumed for previous studies. With the high Q_x optics and the Pretzel running, the luminosity remains essentially stable at a value above $10^{31}/\text{cm}^2/\text{s}$ for up to 10 hours, after which it begins to drop. This situation is much more favorable than anticipated, when it comes to fold the polarization lifetime with the luminosity curve to obtain the effective polarization over a physics run.

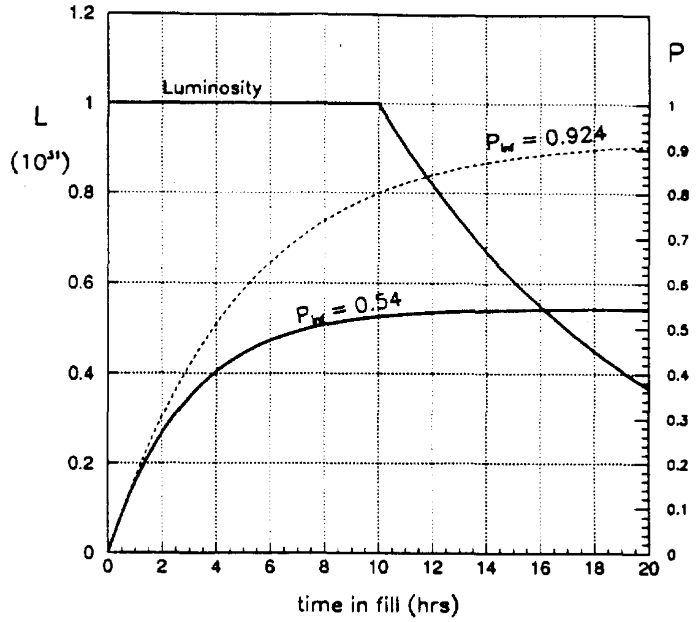


Figure 1: *Time development of luminosity and polarization during a LEP fill. The luminosity curve models the present LEP performance and the polarization curves represent the natural polarization rise, without wigglers, for* $\frac{\tau_p}{\tau_d} = 0.$ *and* $\frac{\tau_p}{\tau_d} = 0.7.$

The error on A_{LR} being

$$\Delta A_{LR} = \frac{1}{\mathcal{P}}\frac{1}{\sqrt{N}}, \tag{5}$$

the effective polarization is given by:

$$\mathcal{P}_{\text{eff}} = \sqrt{\frac{\int_{fill} \mathcal{P}^2(t)\mathcal{L}(t)dt}{\int_{fill} \mathcal{L}(t)dt}}. \tag{6}$$

The time evolution of polarization and luminosity is shown in figure 1.

As usual, the duration of fills can be optimized, given the average time taken from one stable run to the next, to get the best integrated luminosity $\int_{fill} \mathcal{L}(t)dt$. The present run pattern already favors very long runs – 14 hours . The optimum for the polarization figure of merit $\int_{fill} \mathcal{P}^2(t)\mathcal{L}(t)dt$ is somewhat longer – 18 hours – but yields only 3% less integrated luminosity. As a result, a very good effective polarization can be obtained, as shown in figure 2. For $\frac{\tau_p}{\tau_d} = 0.7$, an effective polarization of 0.46 is obtained.

Reducing the polarization time with wigglers is not necessary, contrary to the conclusions drawn in [12] assuming a 3 hours luminosity lifetime. It was shown in 1993 that polarization can be kept [6] with wigglers excited at moderate current, reducing τ_p by a factor of two, but lost for higher excitation. A factor of two in τ_p would increase the effective polarization from 0.46 to 0.50,

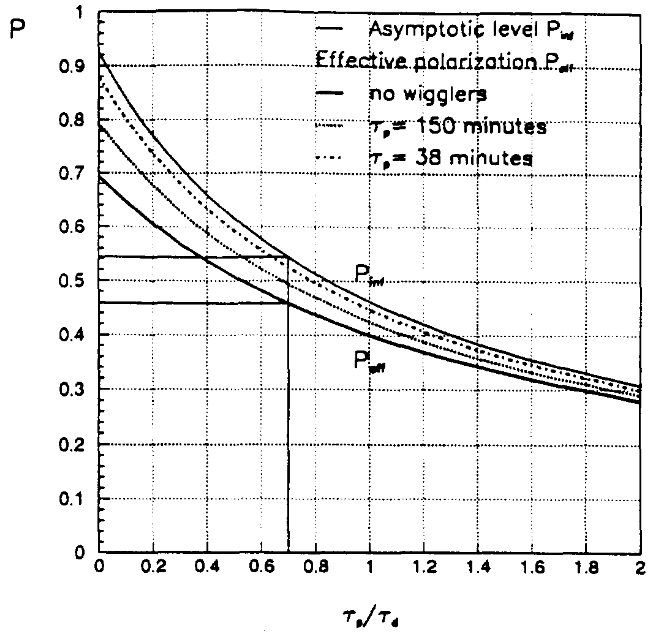


Figure 2: *Effective polarization obtainable in a LEP run as a function of $\frac{\tau_p}{\tau_d}$. Top line: the asymptotic polarization; other lines: the corresponding effective polarization for three different assumptions on how the polarization time can be reduced with wigglers: (from bottom up) no wigglers, reduction by a factor 2, reduction by a factor 8 with the polarization wigglers at full field.*

and could have other beneficial effects for polarization optimization etc... This possibility will be kept in mind as a safety margin, but not used in the following.

2.2 Measurement of A_{LR}

An important asset of LEP is the possibility of polarizing both beams – contrary to SLC where only the e^- can be polarized. Selective depolarization of half of the bunches in each beam is necessary to obtain non-zero e^+e^- helicity. Selective depolarization is now done routinely for energy calibration. This in turn offers the possibility to monitor the polarization of the beams from the data themselves, as described in [13]. The "four-bunch scheme" of reference [13] can be extended trivially to an eight-bunch scheme:

e^-		$\Rightarrow$		$\Rightarrow$		$\Rightarrow$		$\Rightarrow$		
$\longrightarrow$	$\ominus$	$\ominus$	$\ominus$	$\ominus$	$\ominus$	$\ominus$	$\ominus$	$\ominus$	...	
	$\Leftarrow$		$\Leftarrow$		$\Leftarrow$			$\Leftarrow$		e^+
	$\oplus$	$\oplus$	$\oplus$	$\oplus$	$\oplus$	$\oplus$	$\oplus$	$\oplus$	...	$\longleftarrow$
	1	2	1	2	1	2	3	4		

The comparison of the four respective total cross-sections:

$$\sigma_1 = \sigma_u(1 + \mathcal{P}_{e^+} A_{LR}) \tag{7}$$
$$\sigma_2 = \sigma_u(1 - \mathcal{P}_{e^-} A_{LR}) \tag{8}$$
$$\sigma_3 = \sigma_u \tag{9}$$
$$\sigma_4 = \sigma_u(1 - \mathcal{P}_{e^+}\mathcal{P}_{e^-} + (\mathcal{P}_{e^+} - \mathcal{P}_{e^-})A_{LR}) \tag{10}$$

allows a measurement of A_{LR} but also of $\mathcal{P}_{e^+}$ and $\mathcal{P}_{e^-}$ from the data.

An important property of the method is to require only relative cross-section measurements. Systematic errors were reviewed in detail in [3]. The main sources of errors come from the slight differences between the geometrical properties of the eight bunches, affecting the measurement of luminosities with the small angle Bhabha reaction. It was shown that control of these effects should allow a relative luminosity determination with the precision of 10^{-3}, necessary to ensure an error on A_{LR} less than 0.002.

The experience gained since then leads to expect substantial improvements. For example, the systematic errors on cross-section measurements at LEP are already at a level of experimental precision of $\pm 10^{-3}$, both in the selection of hadronic Z decays and in the luminosity measurement. A rapid examination of the error breakdown indicates that the sources of errors relevant to a **relative** cross-section measurement should be of the order of a few 10^{-4}.

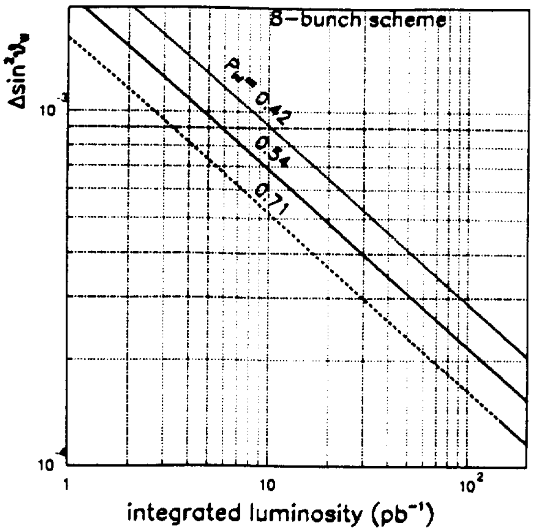
Because currents in all bunches are different, they are submitted to different beam-beam forces, and their polarizations cannot be assumed to be identical. Therefore, the role of the polarimeter is still essential: it should monitor the evolution of the polarization with time and measure the polarization of every bunch of each beam. By repeating the resonant depolarization in a continuous way, complete depolarization for the required bunches can however be safely guaranteed [14]. But what the method provides is the absolute calibration of the polarimeter, with a precision given by statistics, as shown in figure 4.

Note that this method takes care of many sources of systematic errors that affect the measurement of A_{LR} at SLC, arising from the beam polarization measurement itself, and coming from the possible difference between the beam polarization as seen from the polarimeter and the average polarization of the particles interacting at the IP.

The options for polarimetry were studied in "Polarization at LEP" [15], and requirements on the performance spelled out. Here only the bunch-to-bunch systematics on the polarization matter, and should be kept at a level of 0.3%. The transverse polarization in the arcs is equal to the longitudinal polarization in the IP at LEP, otherwise very rapid depolarization would occur. Therefore, the existing LEP transverse polarimeter, with possible improvements as discussed below, can in principle be used. Its statistical power is certainly more than adequate. Whether it provides sufficiently stable measurements should be reviewed in detail. It would need to be replicated for positron polarimetry in any case.

There were several proposals for longitudinal polarimetry in [15]. They offer higher statistical accuracy and lesser dependence on beam parameters, and were expected to meet easily the requirements, ensuring systematic errors from the polarization measurement to be negligible.

The eight bunch scheme sacrifices 25% of the luminosity to control the beam polarization. In practice this fraction of data taken with the helicity configuration "3" or "4" can be optimized to minimize the error on A_{LR}. It is found that the optimum is of 18% for a polarization of 55%, and is



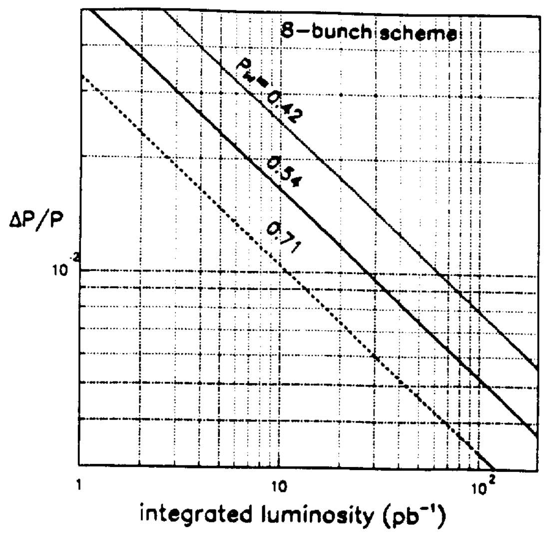


Figure 3: *Precision obtainable on* $\sin^2\theta_w^{\rm eff}$ *as a function of the integrated luminosity with the 8-bunch scheme for three values of the achievable asymptotic polarization degree.*

Figure 4: *Precision obtainable on the polarization as a function of the integrated luminosity with the 8-bunch scheme for three values of the achievable asymptotic polarization degree.*

very broad. The eight bunch scheme is therefore nearly optimal. The scheme can be extended and optimized for any number of bunches in the machine. The precision that can be obtained on $\sin^2\theta_w^{\rm eff}$ as well as the relative precision on the polarization measurement are shown on figures 3 and 4. The contribution to the total error on A_{LR} of the polarization measurement is small in comparison with the purely statistical error on A_{LR}, and scales down with statistics.

We believe that this method could provide a measurement of A_{LR} which is not limited by systematic errors, at least down to a precision of

$$\Delta\sin^2\theta_w^{\rm eff} = \pm 0.0001,$$

resulting from an exposure of 400 pb^{-1}. This ultimate achievement requires four experiments and higher luminosity in LEP. Given i) that the horizontal pretzel presently in operation is consistent with polarization, and ii) that, given substantial but well known upgrades to the machine and the detectors, it can be extended to more bunches, this goal appears eventually achievable.

2.3 The competition

The following facts, however, could lead to the conclusion that longitudinal polarization experiments are not worth undertaking at CERN.

1. The LEP experiments are performing accurate measurements of weak couplings, even without beam polarization.
2. SLC is now in a production phase with beam polarization in excess of 64%, with hopes of reaching 75% or more. The SLD experiment is approved for 10^6 Z's, and hopes to obtain a

measurement of $\sin^2\theta_w^{\rm eff}$ to $\Delta\sin^2\theta_w^{\rm eff} = \pm 0.00027$ [11].

3. The uncertainty on the QED coupling constant at $Q^2 = M_Z^2$ limits the usefulness of the precision measurement of $\sin^2\theta_w^{\rm eff}$.

We will consider these arguments in turn in the following, with the conclusion that a single measurement, with no assumption of universality, and built-in experimental cross-checks is still of considerable value.

2.3.1 SLC

The SLC/SLD collaboration has recently been approved for up to 10^6 Z's with 75% electron beam polarization. The achievable precision on $\sin^2\theta_w^{\rm eff}$ will be:

$$\Delta\sin^2\theta_w^{\rm eff} = 0.0002(stat.) \oplus 0.02 \times \frac{\Delta\mathcal{P}}{\mathcal{P}}. \tag{11}$$

Assuming a systematic error of $\frac{\Delta\mathcal{P}}{\mathcal{P}} = 1\%$, this could give a precision of

$$\Delta\sin^2\theta_w^{\rm eff} = \pm 0.00027. \tag{12}$$

The only draw-back of the SLC/SLD measurement is the total reliance on the beam polarization measurement. Because only the electrons are polarized, the measurement is based on equation 8

$$\sigma_2 = \sigma_u(1 - \mathcal{P}_e\text{-}A_{LR})$$

with beam polarization reversal. The internal cross-check provided by equation 10 is impossible. The polarization of the interacting electrons has to be estimated from a measurement on the electron beam, away from the interaction point, by a Compton polarimeter. Measuring a beam polarization with a precision of 1% in absolute terms is a challenge. Furthermore, the polarization of the SLC beam is not uniform within the electron bunch, and depends on local beam optics. As a result there exists a difference between the polarization of the electrons that interact at the IP, and those sampled by the laser at the Compton polarimeter. These effect require subtle corrections of several percent based on the understanding of the spin transport and of the beam-beam dynamics.

Clearly such effects will be there in LEP as well, but attenuated by orders of magnitude due to the less intense focusing at the IP. Furthermore, the calibration provided by equation 10 really calibrates the polarization of the interacting electrons.

Given the importance of the measurement, we believe that another experiment with better internal cross-check and, in any case, very different systematic errors, is necessary.

2.3.2 LEP

The most precise determination of weak mixing angle $\sin^2\theta_w^{\rm eff}$ is presently obtained from the forward-backward asymmetries at the Z peak, and from the tau lepton polarization and polarization asymmetry:

$$A_{FB}^{(f)} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f \tag{13}$$

$$\mathcal{P}_\tau = -\mathcal{A}_\tau \tag{14}$$

$$A_{FB}^{pol(\tau)} = -\mathcal{A}_e \tag{15}$$

The values of $\sin^2\theta_w^{eff}$ obtained from the LEP experiments so far, on statistics of typically 1.2 10^6 Z's per experiment, are given in table 1 [19]. Statistical errors are still dominant for at least the lepton asymmetries and the b-quark asymmetry, so that adding the data taken in 1993 and a possible 60 pb^{-1} for 1994, a precision between 3-4 10^{-4} could be achievable. This procedure, of course, assumes lepton and quark universality. However, extreme care should be taken when averaging over four experiments, and over so many channels that each individual analysis has a statistical precision at least two times worse than the average of the previous year.

	$\sin^2\theta_w^{eff}$
$A_{FB}^{(\ell)}$	0.2318 ± 0.0010
$\mathcal{P}_\tau$	0.2325 ± 0.0018
$A_{FB}^{pol(\tau)}$	0.2337 ± 0.0032
$A_{FB}^{(b)}$	0.2322 ± 0.0011
$A_{FB}^{(c)}$	0.2313 ± 0.0036
$\langle Q_{FB}\rangle$	0.2320 ± 0.0016
Average	0.2321 ± 0.0006

Table 1: *Comparison of several direct determinations of* $\sin^2\theta_w^{eff}$ *from asymmetries. The average is obtained as a weighted average assuming no correlations. The* $\chi^2/(d.o.f.)$ *of the average is 0.5/5.*

Here again, a single measurement, with no assumption of universality, a build-in experimental cross-check and a pre-defined experimental procedure appears of considerable value.

2.3.3 Theoretical uncertainties

The weak mixing angle $\sin^2\theta_w^{eff}$ is defined in terms of the QED corrected Z pole lepton asymmetry [18], or equivalently from A_{LR}. There is very little uncertainty in the very small QED corrections needed to extract the Z pole value of A_{LR} from the measured quantity [20, 21]. The theoretical Bhabha cross-section predictions do not depend on the beam polarization in the Born approximation, and possible higher order effects are being calculated [22].

The interpretation of the result in terms of the more interesting electroweak radiative corrections, sensitive to e.g. the top quark and Higgs boson masses, requires the understanding of the relation between $\sin^2\theta_w^{eff}$ and the best measured quantities α, G_F and M_Z.

$$M_Z^2 = \frac{\pi\alpha}{\sqrt{2}G_F(1-\Delta\alpha)(1+\Delta\rho)(1+\Delta_{3Q})\sin^2\theta_w^{eff}\cos^2\theta_w^{eff}}, \quad (16)$$

where $\Delta\alpha$ represents the running of the QED coupling constant α from $Q^2 = 0$ to $Q^2 = M_Z^2$, and Δ_{3Q}, $\Delta\rho$ represent the weak isospin-conserving and violating electroweak corrections [23] (these are closely related to ϵ_1 and ϵ_3 of ref. [24]). $\Delta\rho$ itself can also be extracted from measurement of the Z width. In the Minimal Standard Model, $\Delta\rho$ is sensitive to both the top quark and the Higgs boson mass, while Δ_{3Q} is more specifically sensitive to the Higgs mass. It can be shown that $\sin^2\theta_w^{eff}$ is the observable most sensitive to the Higgs mass [25].

Of course extracting the electroweak corrections from $\sin^2\theta_w^{eff}$ can only be done as well as one evaluates $\Delta\alpha$. The hadronic contribution to $\Delta\alpha$ requires integration by a dispersion relation of the cross-section of $e^+e^- \rightarrow$ hadrons from $Q^2 = 0$ to $Q^2 = M_Z^2$. The error on $\Delta\alpha$ results from uncertainties in the measured cross-sections.

Such an evaluation was performed in 1988 [26] leading to an error $\Delta(\Delta\alpha) = \pm 0.0009$ equivalent to $\Delta \sin^2 \theta_w^{\text{eff}} = \pm 0.0003$. Recent work by Jegerlehner and Burkhardt [27] using data available since then leads to an error $\Delta(\Delta\alpha) \leq \pm 0.0007$ equivalent to $\Delta \sin^2 \theta_w^{\text{eff}} = \pm 0.0002$. The hadronic cross-sections can certainly be remeasured at existing or future e^+e^- factories working in the charm threshold region in particular, so that this error – which limits the interpretation of measurements of all asymmetries at LEP, and also of the W mass – can be reduced further. Therefore we do not believe that this uncertainty can be used as an excuse not to push precision measurements further when possible.

3 Towards Experiments With Longitudinally Polarized Beams at LEP

Having shown the fundamental interest of longitudinally polarized beams for LEP, the question arises of their implementation. A detailed study was presented already in 1991 in a previous report [30], discussing the implementation of longitudinal polarization for the four LEP experiments. We will discuss here a more modest step, that would have to be taken in any case before a larger scale programme were launched. Given the time delay of two years required for construction and installation of large spin rotators, it is important, if one wants to leave this possibility open, that the preparatory tests be performed before the beginning of the LEP200 programme.

Two critical elements are still missing to make experiments with longitudinally polarized beams feasible:

1. Polarization can be kept with colliding beams.
2. Spin rotation can be performed with limited loss of polarization, while keeping good experimental conditions.

The first point is, from the point of view of accelerator physics, the least well understood. Spin-matching conditions for beam-beam interaction have been proposed [28], but not implemented. Several physics experiments, such as the measurement of transverse polarization asymmetry at SPEAR [29], were performed in the past with high luminosity and polarization simultaneously. This question can, to a large extent, be studied with transverse polarization after careful theoretical investigation. This test does not require any additional hardware, and it seems urgent to perform it as soon as possible. Allocation of appropriate MD time and support for the required theoretical calculations are needed. **We request that a study of transverse polarization with colliding beams be made as early as possible in 1994.**

Polarization with colliding beams in physics conditions could also be of great value for future energy calibration purposes.

The second point has been studied extensively [30] with the same first order theory that was used for the successful spin-matching of solenoids and lattice defects. A description of such a rotator is given in the next section. Cautious confidence is in order, even though the answer will not come before a spin rotator is built and tried.

3.1 A Test Spin Rotator

A preliminary design of a Richter-Schwitters Spin Rotator [31] RSSR spin-matched for a nominal energy corresponding to the Z peak, has been calculated [33]. The rotator is by construction incompatible with running **longitudinally polarized** beams at a different energy. The rotator insertion is nevertheless designed to be optically compatible with running unpolarized beams at energies up to about 70 GeV. The vertical tilt of the beam axis with respect to the nominal LEP plane at the RSSR center, as required for rotating the spin into a longitudinal direction, is 15.2 mrad. The feasibility of installing the spin rotator in LSS1 has been considered taking into account the presence of the LEP Compton Polarimeter and the existence of sufficient infrastructure to house a small experiment. If located in LSS1 (beam height 0.8 m) the compact rotator fits into the existing LEP tunnel. The proposed layout, shown in Figure 5, makes use of spare concrete LEP cores for which windings would have to be provided. Their maximum field of 0.14 T allows beam operation up to about 70 GeV for the commissioning of the superconducting RF system for the LEP-200 programme. Full compatibility with high luminosity running might require vertical separators around the interaction point. These are not included so far in the design.

To minimize costs no superconducting quadrupoles are foreseen in the low-β insertion. The optical and spin-matching requirements are met with eight existing MQ-type LEP quadrupoles in addition to the standard optical elements already present in an odd straight. Nevertheless, a low-β insertion can be obtained ($\beta_x^* = 1.5$ m, $\beta_y^* = 0.08$ m). The free space at the intersection is ± 4.5 m.

The polarization levels of this spin rotator, have been calculated with a non-linear spin algorithm [34] that has been shown to give reliable results for the optics tested experimentally so far. The predicted polarization levels do not differ significantly from those of a flat machine, i.e. over 80% for ideal optics, without element position errors. It has been checked on simulations that correction of lattice errors by harmonic spin-matching can be done succesfully in presence of the spin-rotator. This means that the real machine with a spin rotator should allow the same polarization levels as presently observed.

3.2 Instrumentation of the Spin Rotator Area

3.2.1 Polarization measurement

Transverse polarization in the accelerator can only be maintained if the spin rotation mechanism is understood in great detail. Therefore we consider that it is sufficient to measure the level of transverse beam polarization outside the spin rotator. With this approach one can make use of the experience gained on the existing polarimeter, and of a large part of the present layout [9].

The light from a single Laser in the optical laboratory close to IP1 would be split into two beams in the LEP tunnel and directed towards the electron and positron Laser Interaction Regions (LIRs) after proper light polarization tuning. The inside-vacuum mirror insertions for the e^+-side LIR have to be constructed and some additional optical components are required in the two longer laser lines to provide adequate light focusing at the two LIR'S displaced outside the rotator insertion.

By moving the laser interaction regions closer to the Compton photon detector the polarimeter becomes less sensitive to aperture limitations in the backscattered γ-line originating from small changes in the electron or laser beam parameters.

The $0.6\%/\sqrt{\text{minute}}$ statistical accuracy in the measurement of the degree of polarization attainable with the present laser system can be considered sufficient to continuously and simultaneously monitor several electron and positrons bunches.

LEP offers a combination of three methods to determine the absolute calibration of the polarimeter.

1. Monte Carlo simulation of the Compton polarimeter including the beam optics and the response of the calorimeter to the backscattered photon beam.

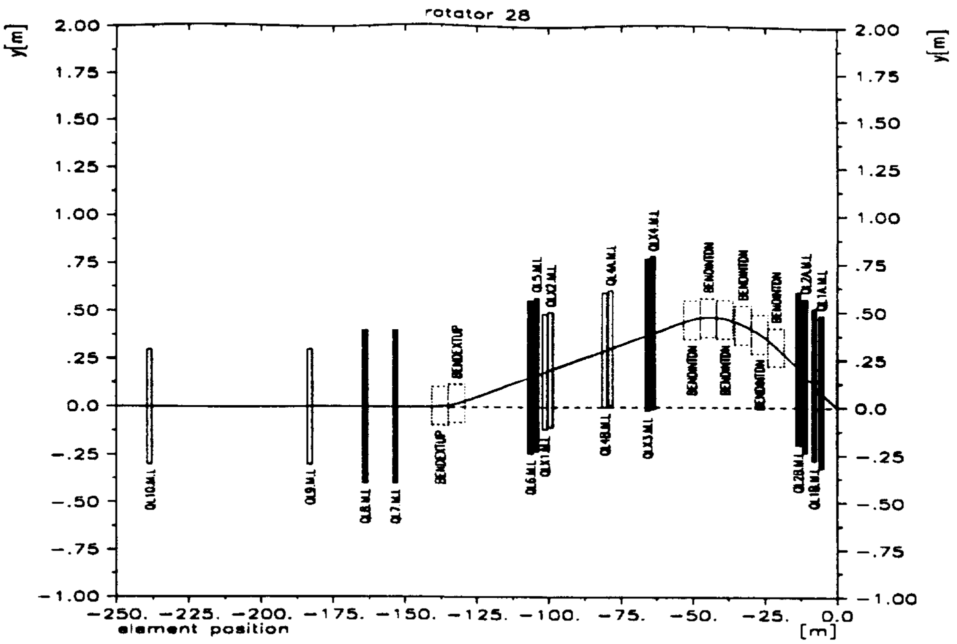


Figure 5: *Preliminary layout of the proposed R.S. spin rotator compatible with high energy unpolarized beams up to* $\sim$ 70 *GeV.*

2. Calibration on the Sokolov-Ternov polarization rise time, equation 4. This method has been extensively used during the last years at LEP and a precision of $\Delta\mathcal{P}/\mathcal{P} = 5\%$ has been achieved so far [32], as illustrated on figure 6. A reasonable agreement at the level of 10% has been found with the monte-carlo prediction. Clearly this method profits from high levels of polarization. With regular measurements at high polarization levels and the foreseen improvements to the polarimeter, this method should provide an absolute calibration at the level of $\geq 1\%$.
3. Measurement of the P^2 term in the e^+e^- annihilation when both beams are polarized, using the 8-bunch scheme as discussed above. As stressed previously this method really tests the polarization of the interacting particles. Here bunch-to-bunch systematic errors are the relevant ones: a difference in calibration of $\Delta\mathcal{P} \leq 3 \times 10^{-3}$ between different bunches of the same sign is required [15]. Given that the polarimeter provides internal control on the relevant beam parameters, beam divergence and tilt in both planes, and for each bunch type, we expect the transverse polarimeter to be very adequate. A more quantitative study for the actual setup with a spin rotator will be made.

3.2.2 Background monitors

One of the main worries in the Richter-Schwitters spin rotators is the large amount of synchrotron emitted by the dipoles near the interaction point. In order to monitor the background levels in a way that is as similar as possible to that performed in the LEP experiments, one could use the same Small Angle Monitors for BAckground (SAMBA) that are presently used in ALEPH. It is important that these detectors be situated as in the LEP experiments, inside a shielding provided by

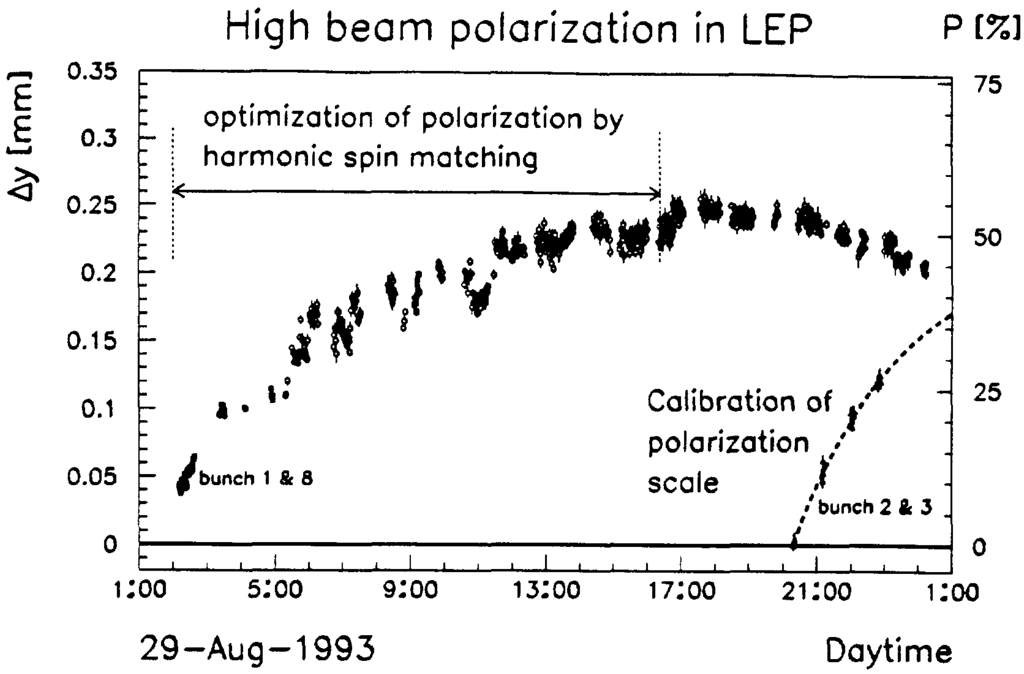


Figure 6: *For measurement of the temperature dependence of the LEP energy scale, polarization was kept for 23 hours and a polarization level of 57% was achieved. At the end of the experiment the polarization scale was calibrated by depolarizing two of the eight bunches and measuring the radiative polarization rise-time [6].*

calorimeters. The Z counters presently envisaged should play this role (see the relevant subsection).

3.2.3 Luminosity measurement

The LEP experiments have acquired considerable experience in the luminosity measurement using low angle Bhabha scattering. The most recent luminosity detectors at LEP [35] are approaching an **absolute** luminosity measurement precision of 10^{-3}. The proposed experiment needs a similar precision in the measurement of the **relative** luminosity from bunch to bunch, as studied in detail in "Polarization at LEP" [36]. This is somewhat less demanding since a very high precision is not required for the absolute position of geometrical limits of the detector.

On the other hand, the variation of the interaction region parameters for different bunches may be larger in this experiment than in the normal LEP operation due to the depolarization of selected bunches. In addition, the backgrounds might vary from one bunch to another. Therefore we need a detector allowing good background rejection as well as a good measurement of the interaction point parameters. In order to fulfill these requirements we are studying a set of two luminosity calorimeters made of 24 radiation lengths of lead-scintillator sandwich, with a tentative sampling every 2 radiation lengths (to be defined later by MC studies). We intend to install one plane of silicon detectors within the stack to measure the position of the shower. We expect the energy resolution of this calorimeter to be approximately $25\%/\sqrt{E}$.

The silicon plane will define the geometrical acceptance of the detector, which will be located at about ± 350 cm (z_0) from the interaction point. The sensitive silicon region will be located between 6.1 and 14.5 cm from the beam line corresponding to the angular region between 17 and 41 mrad. This plane will be divided into 16 cylindrical pad rows and 32 sectors in azimuth. In order to reduce the sensitivity of the luminosity measurement to the vertex position, the LEP experiments define "tight" and "loose" acceptance regions which are alternated from side to side from event to event. The proposed detector could define a reasonable "tight" acceptance region, in the angular range between 23 and 32 mrad, and a "loose" acceptance corresponding to 19 and 40 mrad. The Bhabha cross-section within this acceptance is 109 nb which is similar to the cross-section of the present LEP silicon-tungsten calorimeters. The "tight" - "loose" acceptance difference is larger here than typically used in LEP silicon-tungsten detectors, allowing for the 2.5 times wider electromagnetic shower size in lead with respect to tungsten.

The alternated "tight" and "loose" acceptance method makes the luminosity measurement independent of the bunch vertex position to first order for quite wide excursions of the beam position [37]. In the proposed geometry, only second order errors enter for beam position differences up to 7.5 mm in x and 33 cm in z.

Beam Orbit Monitors (BOM's) will be used to continuously measure the relative mean bunch positions with a precision of $10\mu m$ and the relative mean bunch angles with a precision of $5\mu rad$. The luminosity detector should measure the x,y position of each of the 8 bunch crossings for the integrated luminosity of 10 pb^{-1} with a precision of 25 μm, and the difference in mean angles between bunches with a precision of 0.1 mrad. The precision of these parameters both from the BOM's and from the luminosity detector itself should safely limit the quadratic errors (formulae in the Ref. [37]) on the relative luminosity measurements to below 10^{-3}.

Differences in the angular divergences and beam size between different bunches could occur as well. The beam emittance for different bunches can be measured with the synchrotron light monitor BEUV and with the polarimeter with an instantaneous precision of a few percent. This again should be much better than the 50% differences sufficient to keep relative luminosity errors below 10^{-3}.

The BOM, BEUV and polarimeter measurements can be continuously monitored during data taking. Bunch-to-bunch differences can be reduced significantly by equalizing bunch currents. Measurements of these parameters allow the application of corrections which will keep the relative error well below 10^{-3}.

Off-momentum beam particle backgrounds can be measured and rejected using the same techniques employed by the LEP collaborations. The Bhabha event selection will be based on energy cuts. The energy resolution of the envisaged detector is more than adequate, being better than the one of the LEP silicon-tungsten detectors. The remaining background can be reduced further by cutting on the difference in the azimuthal angles of the two showers. Studies of delayed or fake coincidences, and of the acoplanarity distribution, should allow control of the backgrounds to the desired accuracy.

3.2.4 Detection of Z decays

The left-right asymmetry is, up to small and well known corrections, identical for all Z decays, with the exception of the electron final state where the polarization independent t-channel contribution dilutes the asymmetry. The detection of Z decays requires a rather simple detector providing the following.

- High efficiency for Z→ hadrons events which constitute 85% of visible Z decays.
- Some separation of Z→ e^+e^- decays.
- Good rejection of physics ("two-photon" events), cosmic and beam-induced backgrounds.
- Resistance to radiation.

A high efficiency for hadronic Z decays can easily be achieved with a 20 radiation length calorimeter of moderate energy resolution. Tracking is not necessary and not obviously feasible in an environment with potentially high background. However, background monitoring is important and will be provided, as mentioned before. A total energy resolution of ± 15 GeV for well contained events is sufficient to keep physics backgrounds below 1%. Provided that the acceptance is symmetric in the polar angle, it cancels out for the measurement of A_{LR}. Small effects could occur if the detector is both charge asymmetric *and* polar angle asymmetric, due to the large forward-backward asymmetries with polarized beams. Charge asymmetry can result from different absorption cross-sections for opposite sign final state hadrons (e.g. proton vs anti-proton) but is expected to be largely washed out in an inclusive measurement, so that folding it with a possible polar angle asymmetry is expected to result in systematic effect on A_{LR} of less than 1%.

Since final state identification is not necessary, a coarse granularity is sufficient. Separation and localization of single track events (Bhabhas and cosmics) against hadronic jets will be useful for several reasons:

1. Background rejection.
2. Bhabha event identification for energy calibration and determination of the interaction point.
3. Cosmic ray reconstruction for calorimeter calibration.

We are presently investigating the possibility of building an iron calorimeter, with an azimuthal and polar angle symmetric acceptance of around 90% of 4π. Iron provides better absorption of hadronic showers for a given number of radiation length than, say, lead, while keeping the total depth of the calorimeter compatible with the tight space constraints of an odd intersection point. The exact geometry and read-out material are not fully decided yet. Two possibilities for the read-out are being actively investigated at the moment.

1. An iron-scintillator sandwich with 2 radiation length sampling, figure 7 and 8. The read-out by photo-multipliers could be organized in two read-outs in depth, four in ϕ, and 12 in θ, giving a total of 100 channels. The fine segmentation for single track events would be provided by planar proportional chambers situated two radiation lengths deep inside the calorimeter. The barrel part has an inner radius of 20 cm, an outer radius of 60 cm and a length of 100 cm. The detector could be closed by endcaps of similar construction or by plugs with scintillating fiber read-out.
2. An iron-wire-chamber calorimeter, figure 9 and 10, of cylindrical geometry, inner radius 18 cm, outer radius 75 cm, with 20 iron tubes of 1 radiation length thickness, interleaved with proportional tubes with wire and cathode readout. This construction is very similar to the ALEPH Electromagnetic calorimeter. A total length of 1.6 meters would provide 90% efficiency for hadronic events. The wire chamber readout offers excellent granularity possibilities, and most of the read-out and trigger electronics already exists.

Either one of these designs seems adequate, and feasible, at first sight. Of course detailed simulation of the response to Z decays will be necessary. The final choice is to be made after the physics performance and the practicality of either solution – especially in view of the rather tight

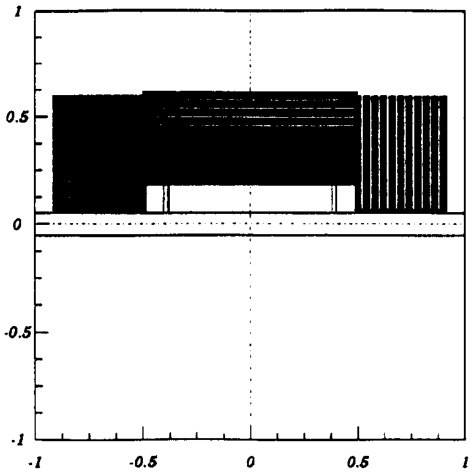


Figure 7: *r-z view of the iron structure in the iron scintillator sandwich detector presently considered. The scale in meters is indicated. A higher precision wire chamber is planned after the first iron plane. A background monitor (SAMBA) is foreseen inside the calorimeter.*

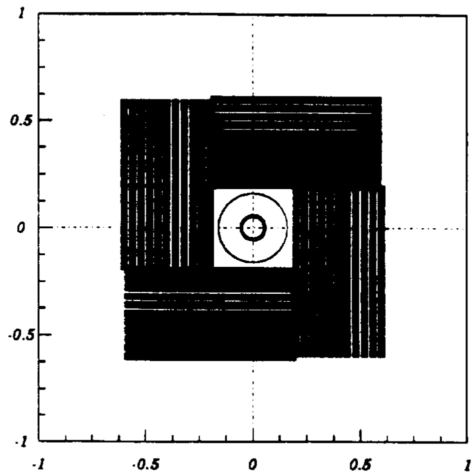


Figure 8: *x-y view of the iron structure in the iron scintillator sandwich detector.*

schedule – is established.

3.3 Infrastructure and installation

The techniques involved for the foreseen detectors are all well established. Detectors matching the physics requirements can certainly be built in the given time scale, and fit in the space available at LSS1 without additional civil engineering. No dangerous gases, magnetic field or cryogenics are necessary. A total weight of around 12 tons is to be foreseen and should be well supported by the existing tunnel floor. The detector designs are compatible with any LEP bunch schemes presently considered to increase the luminosity. The existing infrastructure around LSS1 seems adequate to house a small counting room.

The main requirement concerns the background. It is well known that RSSR creates a large amount of synchrotron radiation in the vertical plane. Existing collimators can be used to absorb the direct radiation. Re-scattered photons can still constitute an important background, even for a calorimetric device. An estimate of the background with the final rotator setup will be needed, to see if further shielding against radiation is necessary. Further shielding can be done either by adding one radiation length of lead on the beam-facing parts of the calorimeter, or by additional masks inside the beam pipe. Global shielding of the interaction area has to be foreseen.

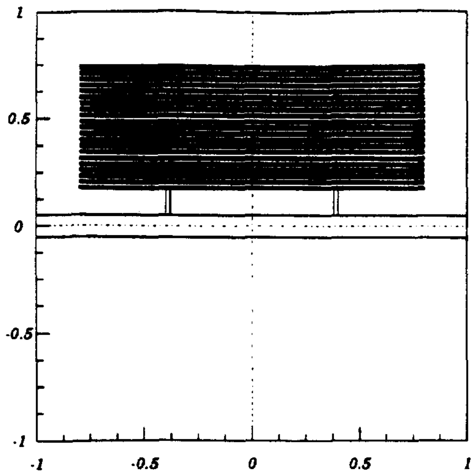


Figure 9: *r-z view of the iron structure in the cylindrical wire-chamber-iron sandwich detector presently considered. The scale in meters is indicated. A background monitor (SAMBA) is foreseen inside the calorimeter.*

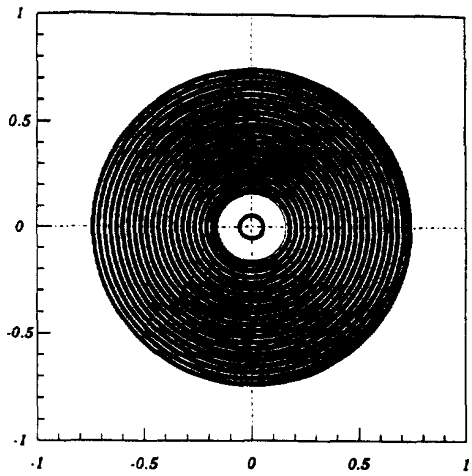


Figure 10: *x-y view of the iron structure in the cylindrical wire-chamber-iron sandwich detector.*

3.4 Costs and time scale

3.4.1 Construction

A preliminary cost estimate for the proposed test set-up is around 2.2 MCHF for the rotator itself (including upgrades to the polarization measurement) and about 1.3 MCHF for the detectors. These figures are based on the assumption that the RSSR and the detector can be accommodated at the IP1, where important existing infrastructure can be used.

Concerning the Z counter and luminosity detectors, the responsibilities for the design and simulation (and at a later stage, the possible construction and operation) are presently being distributed among the interested institutions. Most of the financing is expected to come from outside CERN.

The polarimeter upgrade would be under the responsibility of the present LEP polarization collaboration.

The construction and financing of the rotator would come from CERN.

The design of the rotator and detectors have been simplified as much as possible.

If a positive decision were made in June 1994, the target date for the hardware to be ready would be April to June 1995. The rotator and the detector could then be installed and/or removed during one of the technical stops foreseen for RF installation.

3.4.2 Running time

Understanding the integrated luminosity achievable with polarization is one of the goals of the proposed experiment, so only very tentative figures can be proposed.

It is estimated that around four weeks would be needed to commission the rotator and reach acceptable luminosity and longitudinal polarization simultaneously.

Then, depending on the figures achieved and on the physics priorities at the time, a first measurement of the left-right asymmetry could be performed. If one assumes a reducing factor of about 5 in the attainable luminosity, with respect to the 1993 LEP running ($\sim$ 3 pb^{-1}/week), to account for i) higher β_y^*, ii) possibly a factor $\frac{2}{3}$ in the bunch populations and running with only four bunches, one obtains a conservative estimate of ~ 0.6 pb^{-1}/week for the luminosity with polarized beams. A minimum polarization-weighted figure $\int P^2 Ldt = 1$ pb^{-1} and 5 pb^{-1} total integrated luminosity could then be obtained for a running time of 8 weeks. This would provide a measurement of $\sin^2\theta_w^{\text{eff}}$ with a precision of typically $\leq \pm 0.001$. This test could take place in the second half of 1995.

Simultaneous running of the test set-up with the existing LEP experiments in high luminosity mode would probably be inefficient for everyone, and we would rather suggest separate dedicated running for polarization. The rotator insertion is nevertheless compatible with the running-in of the LEP200 RF system, perhaps a time where high luminosity running for the major experiments would be inefficient.

4 Conclusions

The interest of longitudinal polarization in LEP was reconsidered in view of recent progress. It appears that the measurement of A_{LR} at LEP can be made essentially free of systematic errors, offering eventually the most precise and systematically safest measurement of the weak mixing angle.

The first step is to understand what degree of beam polarization can be sustained with luminosity conditions. We therefore request that the effect of beam-beam collisions on the transverse polarization be studied as soon as possible.

The next step is the installation of a minimal spin rotator set-up with the aim of commissioning LEP with longitudinally polarized beams in collisions.

To demonstrate the feasibility of LEP operation with a reasonable level of polarization and luminosity the test rotator should be instrumented with background monitors, luminosity counters and a rudimentary Z counter. This would allow to gain experience on the experimental conditions in a rotator area, and could provide an interesting measurement of A_{LR}. We further believe that such a test would significantly enhance the physics potential of LEP, opening the possibility of a future run with longitudinally polarized beams.

The construction, installation and operation of the proposed short Richter-Schwitters Spin Rotator and of its instrumentation are technically feasible with reasonable manpower, financial resources and time scale. If located in LSS1 (beam height 800 mm) no excursion into the floor of the LEP tunnel is required. The rotator insertion is compatible with tests of RF cavities up to beam energies of at least 70 GeV.

Rotator and detectors could be installed during one of the machine stops foreseen for the installation of the LEP200 RF system and commissioned during the start-up period for the new cavities.

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